CALIFORNIA ENERGY COMMISSION

Large HVAC Field and Baseline Data

Field Data Collection:
- Site Survey Data Form (product 3.2.3)
- Site Survey Letter (product 3.2.3)
- Site Survey Schedule (product 3.2.3)

Sensitivity Analysis (product 3.3.1)

Solutions Report (product 3.3.3)

TECHNICAL REPORT

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Gray Davis, *Governor*

CALIFORNIA ENERGY COMMISSION

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<u>Project Management</u>: Cathy Higgins, Program Director for New Buildings Institute and Don Aumann, Contract Manager for the California Energy Commission. Additional review was provided by Alan Cowan and Jeff Johnson, New Buildings Institute.

PREFACE

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

This document is one of 33 technical attachments to the final report of a larger research effort called *Integrated Energy Systems: Productivity and Building Science Program* (Program) as part of the PIER Program funded by the California Energy Commission (Commission) and managed by the New Buildings Institute.

As the name suggests, it is not individual building components, equipment, or materials that optimize energy efficiency. Instead, energy efficiency is improved through the integrated design, construction, and operation of building systems. The *Integrated Energy Systems: Productivity and Building Science Program* research addressed six areas:

- Productivity and Interior Environments
- Integrated Design of Large Commercial HVAC Systems
- Integrated Design of Small Commercial HVAC Systems
- Integrated Design of Commercial Building Ceiling Systems
- Integrated Design of Residential Ducting & Air Flow Systems
- Outdoor Lighting Baseline Assessment

The Program's final report (Commission publication #P500-03-082) and its attachments are intended to provide a complete record of the objectives, methods, findings and accomplishments of the *Integrated Energy Systems: Productivity and Building Science Program*. The final report and attachments are highly applicable to architects, designers, contractors, building owners and operators, manufacturers, researchers, and the energy efficiency community.

This attachment, "Large HVAC Field and Baseline Data"(Attachment A-21), provides supplemental information to the program's final report within the **Integrated Design of Large Commercial HVAC Systems** research area. It includes three reports:

1. **Field Data Collection**
   - **Site Survey Letter.** A form letter used to request preliminary data about the buildings selected for the onsite surveys.
   - **Site Survey Schedule.** A form used by the project researchers to gather information about the facility in preparation for the site visit.
   - **Site Survey Data Form.** A form used for gathering information collected during the site visits.
2. **Sensitivity Analysis.** Describes the computer simulations of a 105,000-ft^2 office building performed to estimate the range of impacts for measures that the researchers planned to be cover in Advanced VAV System Design Guidelines.

3. **Solutions Report.** Documents the analysis of fan selection and control issues, including the impacts of fan type selection, fan sizing and supply pressure reset.

The Buildings Program Area within the Public Interest Energy Research (PIER) Program produced these documents as part of a multi-project programmatic contract (#400-99-413). The Buildings Program includes new and existing buildings in both the residential and the non-residential sectors. The program seeks to decrease building energy use through research that will develop or improve energy efficient technologies, strategies, tools, and building performance evaluation methods.

For other reports produced within this contract or to obtain more information on the PIER Program, please visit www.energy.ca.gov/pier/buildings or contact the Commission's Publications Unit at 916-654-5200. All reports, guidelines and attachments are also publicly available at www.newbuildings.org/pier.

ABSTRACT

This set of three reports is part of the Integrated Design of Large Commercial HVAC Systems research project, one of six research elements of the *Integrated Energy Systems: Productivity and Building Science* Program. This program was funded by the California Energy Commission's Public Interest Energy Research (PIER) Program.

This document contains three reports related to early tasks that the researchers conducted to identify problems and solutions related to the performance of VAV reheat systems in large commercial buildings in California:

1. **Field Data Collection.** This consists of three forms used to gather data about the buildings selected for onsite surveys: a site survey letter, site survey schedule, and site survey data form.

2. **Sensitivity Analysis.** This describes the researchers efforts to quantify problems with controls and operation that cause energy inefficiencies. This included studying the load profiles, controls and system performance to identify improvements, and testing different design approaches using simulations and engineering calculations. The researchers developed a preliminary list of solutions and conducted an analysis of their potential energy impact. Simulations of a 105,000-ft^2 office building were performed to estimate the impacts of measures planned to be covered in the Advanced VAV System Design Guide.

3. **Baseline Phase Solutions Report.** This documents the research that provided a basis for the Design Guide; *actual conclusions and recommendations are in the final Design Guide.* Topics covered are: fan systems, coils, terminal units, demand-control ventilation, internal heat gain, system effects, reheat source and control, supply air temperature control, and night purge.

Authors: Erik Kolderup and Tianzhen Hong, Eley Associates. Mark Hydeman, Steve Taylor and Jeff Stein, Taylor Engineering.

Keywords: HVAC, energy efficiency, variable-air-volume, VAV reheat, chilled water plant, fan systems, coils, terminal units, demand-control ventilation, HVAC control

Integrated Design of Large Commercial HVAC Systems Site Survey

Lead Engineer Initials:	
Date: / /	
Site ID:	

Facility Information

Repeat this form for each facility at a site. A facility is 1 or more buildings served by a chilled water plant.

Facility's primary use			
Climate Zone (Hot/Mild)		City or closest major city	
Gross conditioned floor space		Percent of space currently occupied	%
Date of first occupancy		Date (or expected date) of full occupancy	
Describe any major changes to the facility likely to start during the next 3 years.		If the facility has recording demand meters, describe the best way to obtain these data over the next two years.	

Describe the current status of the facility's HVAC systems. Is operation stable? Is the contractor still doing tuning and adjustment? Are there significant problems and how are they being addressed?	

Take photos of each building in this facility showing basic geometry, typical fenestration and site conditions. *Paste into space below and give each picture an appropriate label.*

Label:	Label:
Label:	Label:

Facility Information *Repeat this form for each facility at a site. A facility is 1 or more buildings served by a chilled water plant.*			
Additional photos:			
Label:		Label:	
Label:		Label:	
Label:		Label:	
Fenestration (approx. +/- 10%)	%	Describe significant site issues affecting cooling load.	

System/Occupancy Areas [Replace checked boxes with solid square when completing electronic copy]

Divide the conditioned space into areas that are served by the same type of HVAC system (CV or VAV) and that have similar occupancy and energy use intensity. Lump minor uses (< 10% of total floor area) with larger areas unless they contain very intense energy uses, e.g., a computer center.

☐VAV ☐CV	Area #1	Primary Use	Special Ventilation Requirements	
	% of conditioned area	Approximate watts/sf (all lights and equipment)		
	Typical operating schedule:			
	Major Electrical Process Equipment		Major Gas Process Equipment	
	☐ Single Duct ☐ Dual Duct	Served by: ☐ VAV chilled water plant ☐ Other source		
	Fan Powered VAV Boxes: ☐ Series ☐ Parallel ☐ Not Powered	Reheat Coil: ☐ Yes➔ ☐ No	☐ steam ☐ hot water ☐ electric	
	Type of separate heating system:			
	Typical Heating Setpoints	Day °F	Night °F	Range of User Control (+/- °F)
	Typical Cooling Setpoints	Day °F	Night °F	Range of User Control (+/- °F)
☐VAV ☐CV	Area #2	Primary Use	Special Ventilation Requirements	
	% of conditioned area	Approximate watts/sf (all lights and equipment)		
	Typical operating schedule:			
	Major Electrical Process Equipment		Major Gas Process Equipment	
	☐ Single Duct ☐ Dual Duct	Served by: ☐ VAV chilled water plant ☐ Other source		
	Fan Powered VAV Boxes: ☐ Series ☐ Parallel ☐ Not Powered	Reheat Coil: ☐ Yes➔ ☐ No	☐ steam ☐ hot water ☐ electric	
	Type of separate heating system:			
	Typical Heating Setpoints	Day °F	Night °F	Range of User Control (+/- °F)
	Typical Cooling Setpoints	Day °F	Night °F	Range of User Control (+/- °F)
☐VAV ☐CV	Area #3	Primary Use	Special Ventilation Requirements	
	% of conditioned area	Approximate watts/sf (all lights and equipment)		
	Typical operating schedule:			
	Major Electrical Process Equipment		Major Gas Process Equipment	
	☐ Single Duct ☐ Dual Duct	Served by: ☐ VAV chilled water plant ☐ Other source		
	Fan Powered VAV Boxes: ☐ Series ☐ Parallel ☐ Not Powered	Reheat Coil: ☐ Yes➔ ☐ No	☐ steam ☐ hot water ☐ electric	
	Type of separate heating system:			
	Typical Heating Setpoints	Day °F	Night °F	Range of User Control (+/- °F)
	Typical Cooling Setpoints	Day °F	Night °F	Range of User Control (+/- °F)

System/Occupancy Areas [Replace checked boxes with solid square when completing electronic copy]

☐VAV ☐CV	Area #4	Primary Use	Special Ventilation Requirements	
	% of conditioned area	Approximate watts/sf (all lights and equipment)		
	Typical operating schedule:			
	Major Electrical Process Equipment		Major Gas Process Equipment	
	☐ Single Duct ☐ Dual Duct	Served by: ☐ VAV chilled water plant ☐ Other source		
	Fan Powered VAV Boxes: ☐ Series ☐ Parallel ☐ Not Powered	Reheat Coil: ☐ Yes➔ ☐ No	☐ steam ☐ hot water ☐ electric	
	Type of separate heating system:			
	Typical Heating Setpoints	Day °F	Night °F	Range of User Control (+/- °F)
	Typical Cooling Setpoints	Day °F	Night °F	Range of User Control (+/- °F)
☐VAV ☐CV	Area #5	Primary Use	Special Ventilation Requirements	
	% of conditioned area	Approximate watts/sf (all lights and equipment)		
	Typical operating schedule:			
	Major Electrical Process Equipment		Major Gas Process Equipment	
	☐ Single Duct ☐ Dual Duct	Served by: ☐ VAV chilled water plant ☐ Other source		
	Fan Powered VAV Boxes: ☐ Series ☐ Parallel ☐ Not Powered	Reheat Coil: ☐ Yes➔ ☐ No	☐ steam ☐ hot water ☐ electric	
	Type of separate heating system:			
	Typical Heating Setpoints	Day °F	Night °F	Range of User Control (+/- °F)
	Typical Cooling Setpoints	Day °F	Night °F	Range of User Control (+/- °F)
☐VAV ☐CV	Area #6	Primary Use	Special Ventilation Requirements	
	% of conditioned area	Approximate watts/sf (all lights and equipment)		
	Typical operating schedule:			
	Major Electrical Process Equipment		Major Gas Process Equipment	
	☐ Single Duct ☐ Dual Duct	Served by: ☐ VAV chilled water plant ☐ Other source		
	Fan Powered VAV Boxes: ☐ Series ☐ Parallel ☐ Not Powered	Reheat Coil: ☐ Yes➔ ☐ No	☐ steam ☐ hot water ☐ electric	
	Type of separate heating system:			
	Typical Heating Setpoints	Day °F	Night °F	Range of User Control (+/- °F)
	Typical Cooling Setpoints	Day °F	Night °F	Range of User Control (+/- °F)

Air Handling [Replace checked boxes with solid square when completing electronic copy]

Are cooling coil bypass dampers for reduced pressure drop when no cooling required present?	☐ Yes ☐ No

Data for each major central air handling unit

☐ Supply ☐ Return ☐ Exhaust	AHU Group #1	# of Units	Fan HP	Serves VAV system ☐ Yes ☐ No
	Volume Control Method	☐ VSD ☐ Inlet Vanes ☐ Variable Pitch Blades ☐ Outlet Damper ☐ Varicone ☐ Other (describe):		
	Economizer controller type	☐ Local ☐ Central ☐ None		
	Volume controller type	☐ Local ☐ Central ☐ None		
☐ Supply ☐ Return ☐ Exhaust	AHU Group #2	# of Units	Fan HP	Serves VAV system ☐ Yes ☐ No
	Volume Control Method	☐ VSD ☐ Inlet Vanes ☐ Variable Pitch Blades ☐ Outlet Damper ☐ Varicone ☐ Other (describe):		
	Economizer controller type	☐ Local ☐ Central ☐ None		
	Volume controller type	☐ Local ☐ Central ☐ None		
☐ Supply ☐ Return ☐ Exhaust	AHU Group #3	# of Units	Fan HP	Serves VAV system ☐ Yes ☐ No
	Volume Control Method	☐ VSD ☐ Inlet Vanes ☐ Variable Pitch Blades ☐ Outlet Damper ☐ Varicone ☐ Other (describe):		
	Economizer controller type	☐ Local ☐ Central ☐ None		
	Volume controller type	☐ Local ☐ Central ☐ None		
☐ Supply ☐ Return ☐ Exhaust	AHU Group #4	# of Units	Fan HP	Serves VAV system ☐ Yes ☐ No
	Volume Control Method	☐ VSD ☐ Inlet Vanes ☐ Variable Pitch Blades ☐ Outlet Damper ☐ Varicone ☐ Other (describe):		
	Economizer controller type	☐ Local ☐ Central ☐ None		
	Volume controller type	☐ Local ☐ Central ☐ None		
☐ Supply ☐ Return ☐ Exhaust	AHU Group #5	# of Units	Fan HP	Serves VAV system ☐ Yes ☐ No
	Volume Control Method	☐ VSD ☐ Inlet Vanes ☐ Variable Pitch Blades ☐ Outlet Damper ☐ Varicone ☐ Other (describe):		
	Economizer controller type	☐ Local ☐ Central ☐ None		
	Volume controller type	☐ Local ☐ Central ☐ None		
☐ Supply ☐ Return ☐ Exhaust	AHU Group #6	# of Units	Fan HP	Serves VAV system ☐ Yes ☐ No
	Volume Control Method	☐ VSD ☐ Inlet Vanes ☐ Variable Pitch Blades ☐ Outlet Damper ☐ Varicone ☐ Other (describe):		
	Economizer controller type	☐ Local ☐ Central ☐ None		
	Volume controller type	☐ Local ☐ Central ☐ None		
☐ Supply ☐ Return ☐ Exhaust	AHU Group #7	# of Units	Fan HP	Serves VAV system ☐ Yes ☐ No
	Volume Control Method	☐ VSD ☐ Inlet Vanes ☐ Variable Pitch Blades ☐ Outlet Damper ☐ Varicone ☐ Other (describe):		
	Economizer controller type	☐ Local ☐ Central ☐ None		
	Volume controller type	☐ Local ☐ Central ☐ None		
☐ Supply ☐ Return ☐ Exhaust	AHU Group #8	# of Units	Fan HP	Serves VAV system ☐ Yes ☐ No
	Volume Control Method	☐ VSD ☐ Inlet Vanes ☐ Variable Pitch Blades ☐ Outlet Damper ☐ Varicone ☐ Other (describe):		
	Economizer controller type	☐ Local ☐ Central ☐ None		
	Volume controller type	☐ Local ☐ Central ☐ None		

Chilled Water Plant **[Replace checked boxes with solid square when completing electronic copy]**

Chiller #1	Make	Model		
Nameplate Tons	Rated Efficiency (kw/Ton)	Fuel Type ☐ Electric ☐ Gas		
Condenser	Type ☐ Air- ☐ Water-cooled	Flow control ☐ VSD ☐ Valve ☐ Constant Flow		
Compressor	Type ☐ Centrifugal ☐ Screw ☐ Reciprocating	Capacity control ☐ VSD ☐ Unloading ☐ None		
Start/Stop Control	Unitary controller (if present)			
☐ Manual ☐ Unitary Controller ☐ Central DDC	Make	Model		
Chiller #2	Make	Model		
Nameplate Tons	Rated Efficiency (kw/Ton)	Fuel Type ☐ Electric ☐ Gas		
Condenser	Type ☐ Air- ☐ Water-cooled	Flow control ☐ VSD ☐ Valve ☐ Constant Flow		
Compressor	Type ☐ Centrifugal ☐ Screw ☐ Reciprocating	Capacity control ☐ VSD ☐ Unloading ☐ None		
Start/Stop Control	Unitary controller (if present)			
☐ Manual ☐ Unitary Controller ☐ Central DDC	Make	Model		
Chiller #3	Make	Model		
Nameplate Tons	Rated Efficiency (kw/Ton)	Fuel Type ☐ Electric ☐ Gas		
Condenser	Type ☐ Air- ☐ Water-cooled	Flow control ☐ VSD ☐ Valve ☐ Constant Flow		
Compressor	Type ☐ Centrifugal ☐ Screw ☐ Reciprocating	Capacity control ☐ VSD ☐ Unloading ☐ None		
Start/Stop Control	Unitary controller (if present)			
☐ Manual ☐ Unitary Controller ☐ Central DDC	Make	Model		
Chiller #4	Make	Model		
Nameplate Tons	Rated Efficiency (kw/Ton)	Fuel Type ☐ Electric ☐ Gas		
Condenser	Type ☐ Air- ☐ Water-cooled	Flow control ☐ VSD ☐ Valve ☐ Constant Flow		
Compressor	Type ☐ Centrifugal ☐ Screw ☐ Reciprocating	Capacity control ☐ VSD ☐ Unloading ☐ None		
Start/Stop Control	Unitary controller (if present)			
☐ Manual ☐ Unitary Controller ☐ Central DDC	Make	Model		
Chiller #5	Make	Model		
Nameplate Tons	Rated Efficiency (kw/Ton)	Fuel Type ☐ Electric ☐ Gas		
Condenser	Type ☐ Air- ☐ Water-cooled	Flow control ☐ VSD ☐ Valve ☐ Constant Flow		
Compressor	Type ☐ Centrifugal ☐ Screw ☐ Reciprocating	Capacity control ☐ VSD ☐ Unloading ☐ None		
Start/Stop Control	Unitary controller (if present)			
☐ Manual ☐ Unitary Controller ☐ Central DDC	Make	Model		
Chiller #6	Make	Model		
Nameplate Tons	Rated Efficiency (kw/Ton)	Fuel Type ☐ Electric ☐ Gas		
Condenser	Type ☐ Air- ☐ Water-cooled	Flow control ☐ VSD ☐ Valve ☐ Constant Flow		
Compressor	Type ☐ Centrifugal ☐ Screw ☐ Reciprocating	Capacity control ☐ VSD ☐ Unloading ☐ None		
Start/Stop Control	Unitary controller (if present)			
☐ Manual ☐ Unitary Controller ☐ Central DDC	Make	Model		
Notes of chiller configuration or features:				

Chilled Water Plant [Replace checked boxes with solid square when completing electronic copy]

Chiller Sequencing	☐ local ☐ central DDC ☐ None						
Chilled water distribution	Loop layout ☐ Primary ☐ Primary/Secondary ☐ Other						
Primary Loop				Secondary Loop			
HP	# of Pumps	VSD	☐Yes ☐No	HP	# of Pumps	VSD	☐Yes ☐ No
HP	# of Pumps	VSD	☐Yes ☐No	HP	# of Pumps	VSD	☐Yes ☐ No
HP	# of Pumps	VSD	☐Yes ☐No	HP	# of Pumps	VSD	☐Yes ☐ No
				HP	# of Pumps	VSD	☐Yes ☐ No
				HP	# of Pumps	VSD	☐Yes ☐ No
				HP	# of Pumps	VSD	☐Yes ☐ No

Cooling Tower	Type ☐ Open ☐ Closed/fluid cooler	Fan HP	Heat rejection tons
Fan Type ☐ Axial ☐ Centrifugal	Fan Speed Control ☐ Multi-speed ☐ VSD ☐ Constant Speed		

Notes of configuration or operation of chilled water plant:

Central Controls [Replace checked boxes with solid square when completing electronic copy]

HVAC Controls	Make	Model	Pneumatic components	☐ Yes ☐ No

Special Control Algorithms

Supply air temperature reset control	☐ Available, but not used ☐ in use ☐ not available
Supply air pressure reset control	☐ Available, but not used ☐ in use ☐ not available

Lighting Controls	☐ Yes ☐ No	If separate Lighting control system	
		Make	Model

Sensors and Trend Logs			Trend Log Attached	Calibration Doc Attached
Chiller #1	Energy	☐ Amp ☐ kW ☐ None	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
	Chilled Water	Supply temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Flow	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Return Temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
	Condenser Water	Supply temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Flow	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Return Temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
Chiller #2	Energy	☐ Amp ☐ kW ☐ None	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
	Chilled Water	Supply temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Flow	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Return Temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
	Condenser Water	Supply temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Flow	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Return Temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
Chiller #3	Energy	☐ Amp ☐ kW ☐ None	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
	Chilled Water	Supply temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Flow	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Return Temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
	Condenser Water	Supply temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Flow	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Return Temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
Chiller #4	Energy	☐ Amp ☐ kW ☐ None	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
	Chilled Water	Supply temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Flow	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Return Temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
	Condenser Water	Supply temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Flow	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Return Temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
Chiller #5	Energy	☐ Amp ☐ kW ☐ None	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
	Chilled Water	Supply temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Flow	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Return Temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
	Condenser Water	Supply temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Flow	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Return Temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
Chiller #6	Energy	☐ Amp ☐ kW ☐ None	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
	Chilled Water	Supply temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Flow	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Return Temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
	Condenser Water	Supply temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Flow	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Return Temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
Chilled Water Distribution		Supply temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Flow	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
		Return Temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA
Outside Air		temp	☐ Yes ☐ No ☐ NA	☐ Yes ☐ No ☐ NA

Central Controls [Replace checked boxes with solid square when completing electronic copy]

Trend log capability and issues	
Can trend logs be exported to a file?	☐ yes ☐ no
What is the capacity of each trend log? Number of readings	
What is the smallest recording interval, e.g., 1-minute, 15-minute, etc.?	
How many points can the system simultaneously log?	
Can these trend logs be accessed via an Intenet or dial-up connection to the system?	☐ yes ☐ no
Could the operator e-mail trend logs to the study team on a regular basis?	☐ yes ☐ no
Other relevant information about the control system or its ability to do trend logging.	

Documentation Checklist [Replace checked boxes with solid square when completing electronic copy]

☐ Attached ☐ Available on site ☐ Not Available	Energy billing records
☐ Attached ☐ Available on site ☐ Not Available	Mechanical equipment schedule
☐ Attached ☐ Available on site ☐ Not Available	Piping schematic for chilled water plant
☐ Attached ☐ Available on site ☐ Not Available	Manufacturer's test report for each chiller
☐ Attached ☐ Available on site ☐ Not Available	Intended sequence of operation
☐ Attached ☐ Available on site ☐ Not Available	Control system communications riser
☐ Attached ☐ Available on site ☐ Not Available	Control system points list (current system configuration)
☐ Attached ☐ Available on site ☐ Not Available	Electrical rise diagram
Notes on availability of documentation	

Interest in Monitoring [Replace checked boxes with solid square when completing electronic copy]

If selected, can monitoring proceed at this facility?	☐ Yes ☐ No	Reason(s) for No
Conditions or restrictions associated with Yes		

SBW Consulting, Inc.
Energy and Environmental Research

{Date}

{Address}
{Address}
{Address}
{Address}

Dear :

My firm represents the New Building Institute (NBI), which is operating under contract to the California Energy Commission (CEC). The CEC has asked NBI to conduct a program to improve the design and energy efficiency of large facilities that use Variable Air Volume (VAV) air conditioning systems. We have contacted owners and operators of more than 500 large facilities in California and have identified 25 that are best suited for this program.

Over the next two months, we will complete on-site inspections of these 25 facilities so that we can select five for the final phase of this program. At these facilities we will install a performance monitoring system. The system will collect data during the summer and fall of 2001. Our team will analyze this data to identify ways to reduce energy costs. If any are found we will work with the facility management to help make these improvements. The monitoring system will continue to operate through the summer and fall of 2002 to document the effects of these improvements. The results from all five facilities will be used in developing guidelines for design, construction and operations that can be used by facility owners and managers throughout California.

We plan to send one of our senior engineers and an assistant to spend one day in your facility to collect the required information. They will need to meet for about an hour with a person who is familiar with your HVAC equipment and its operation. They will also need about an hour with your control system operator/programmer. In addition, our staff will need access to the chilled water plant and major equipment rooms.

It will greatly simplify the data collection process if we can get some information from your staff before the on-site inspection. Much of this information can be obtained from your facility plans and operator's documentation. Of course, we will arrange for and pay a courier/photo copy service to make a copy of these documents if your staff can tag the appropriate pages. The pages we need are:

- ✓ Control Diagram showing typical VAV box controls
- ✓ Mechanical Equipment Schedule
- ✓ Piping Schematic for Chilled Water Plant
- ✓ Electrical Riser Diagram

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- ✓ System Communications Riser Diagram
- ✓ Intended Sequence of Operations for Air Handlers and Chillers
- ✓ From your operator's documentation we need the Manufacturer’s Test Report for each chiller.

Two other items will also be very useful.

- ✓ Recent electrical and gas bills
- ✓ Brief trend logs for readings from flow and supply/return temperature sensors on the chilled water and condenser water loop (which if available, can be printed out by your control system)

Your assistance with this program is greatly appreciated. If you have any questions or concerns do not hesitate to contact me by phone or e-mail.

Sincerely,

Michael Baker
Vice President
SBW Consulting, Inc.
(425) 827-0330
mbaker@sbwconsulting.com

Integrated Design of Large Commercial HVAC Systems Initial Site Survey

Scheduler Initials:	
Date: / /	
Site ID:	

Scheduling and Pre-Visit Preparations

1. Call the person shown on the telephone-screening interview as the contact for scheduling the site survey. Tell them we are ready to start the next phase of this program — conducting on-site inspection at 25 facilities that have chilled water VAV systems. We would like to fax or e-mail a brief letter (end of this section) which describes this program and the assistance that we need in completing the on-site inspection. Confirm and record their contact information and send the letter via e-mail or fax (as they request).

Primary Contact	
Name:	E-mail:
Title:	Fax:

2. We plan to send one of our senior engineers and an assistant to spend one day in your facility to collect the required information. They will need to meet for about an hour with a person who is familiar with your HVAC equipment and its operation. They will also need about an hour with your control system operator/programmer. In addition, they will need access to the chilled water plant and major equipment rooms. Ask for contact information for the HVAC and controls contacts.

HVAC Contact	Controls Contact
Name:	Name:
Phone Number:	Phone Number:
Pager/Mobile:	Pager/Mobile:
E-mail:	E-mail:

3. If HVAC and Controls contacts are different people ask what the best way is to schedule a day that will work for both of them.

4. We can accomplish our work more quickly and take up less of your valuable staff time, if we can arrange to get copies of selected pages from your electrical and mechanical as-built drawings and operator's documentation. (See list in letter). If you can tag the appropriate pages, we will pay for a courier and photocopy service to make a copy. It would be best if we can get our copy before we arrive at your facility. Do you have a preferred service (record name and phone #)? If not we will make the necessary arrangements.

Preferred photo copy service		
Name:	City:	Phone:

Notes on what Wendy and field staff need to do to complete this process:

5. We also need electric and gas billing data for your facility. Ask what the best way is to get copies of bills for recent months (up to a full year if readily available). If necessary, get contact information for another person in the organization that can make copies of these bills. Have them mailed, faxed or picked up by field staff.

Contact for Copy of Bills	
Name:	E-mail:
Title:	Phone

Notes on what field staff need to do to complete this process:

Scheduling and Pre-Visit Preparations

6. Explain that once we complete surveys of 25 sites, we will select 5 facilities for the final phase of this program. At these facilities we will install a performance monitoring system. The system will collect data during the summer and fall of 2001. Our team will analyze this data to identify ways to reduce energy costs. If any are found we will work with the facility management to help make these improvements. The monitoring system will continue to operate through the summer and fall of 2002 to document the effects of these improvements. If your facility were selected, would you be interested in being one of these monitored sites? Who should we contact in your organization that would be able to authorize your participation in this program

Yes	
No	

Name:	E-mail:
Title:	Pager/Mobile:
Phone Number:	Notes:

7. Talk to the controls contact (may be the same person you are currently speaking with). Provide an overview of the project. Send the letter if appropriate. Explain that we need to evaluate what data can be obtained from the control system. Confirm the presence of flow and supply/return temperature sensors in the condenser and chilled water loops. Explain that we need sample trend logs, running concurrently for a few hours, for each of these sensors. Work out a plan with this contact for capturing these trend logs (electronic/ printed, tabular/plot) and sending them to us (e-mail, fax, field staff picks them up).

Notes on what field staff need to do to complete this process:

8. We also need a current points list for the control system. Work out a plan for getting a current points list, including any definitions of abbreviations.

Notes on what field staff need to do to complete this process:

9. Schedule the on-site work. If the plans cannot be sent to SBW before the site visit, we need access to the plans at the beginning of the day and will not be ready to meet with these contacts until 10 or later. Meetings at all sites must be scheduled before 1pm so there is time to finish work after the meetings.

HVAC contact:	Date:	Time:	Place:
Controls contact:	Date:	Time:	Place:

Notes on scheduling and survey logistics:

Sensitivity Analysis

Integrated Design of Large Commercial HVAC Systems

Deliverable: 3.3.1

May 17, 2002

Prepared for:

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Table of Contents

Summary

Simulations of a 105,000 ft^2 office building were performed to estimate the range of impacts for measures currently planned to be covered in the guidelines. The building represents monitoring site #1 and in some cases preliminary monitored data from that site is used in the analysis.

Figure 1 illustrates the energy cost sensitivity results for each measure. The longer the bar on the graph, the more potential energy impact for the measure. These results are useful for a rough comparison of the importance of individual measures but should not be considered conclusive results. A number of alternatives were evaluated for each measure. Some of the measures are evaluated over a relatively conservative range of options while others cover extremes beyond likely design range.

The analysis shows that supply air temperature control (i.e. reset) has the largest potential individual impact. The high energy case assumes a constant supply air temperature setpoint throughout the year. The lowest energy case assumes that the supply air temperature is reset upwards as high as possible while still satisfying cooling loads in the warmest zone.

Duct sizing, VAV box sizing and fan selection follow supply air temperature control in order of their impact on the building energy use.

Several of the results are reported for two different operating schedules (24/7 vs. 5 days per week) because the hours of operation are significant for the impact of some measures, especially supply air temperature reset and VAV box sizing.

No results are shown for several of the measures because they have not be evaluated. These are either lower priority measures, or they have not been modeled due to time constraints. These measures will be evaluated in the next phase of the study.

Observations and conclusions regarding each measure at discussed at the end of each section.

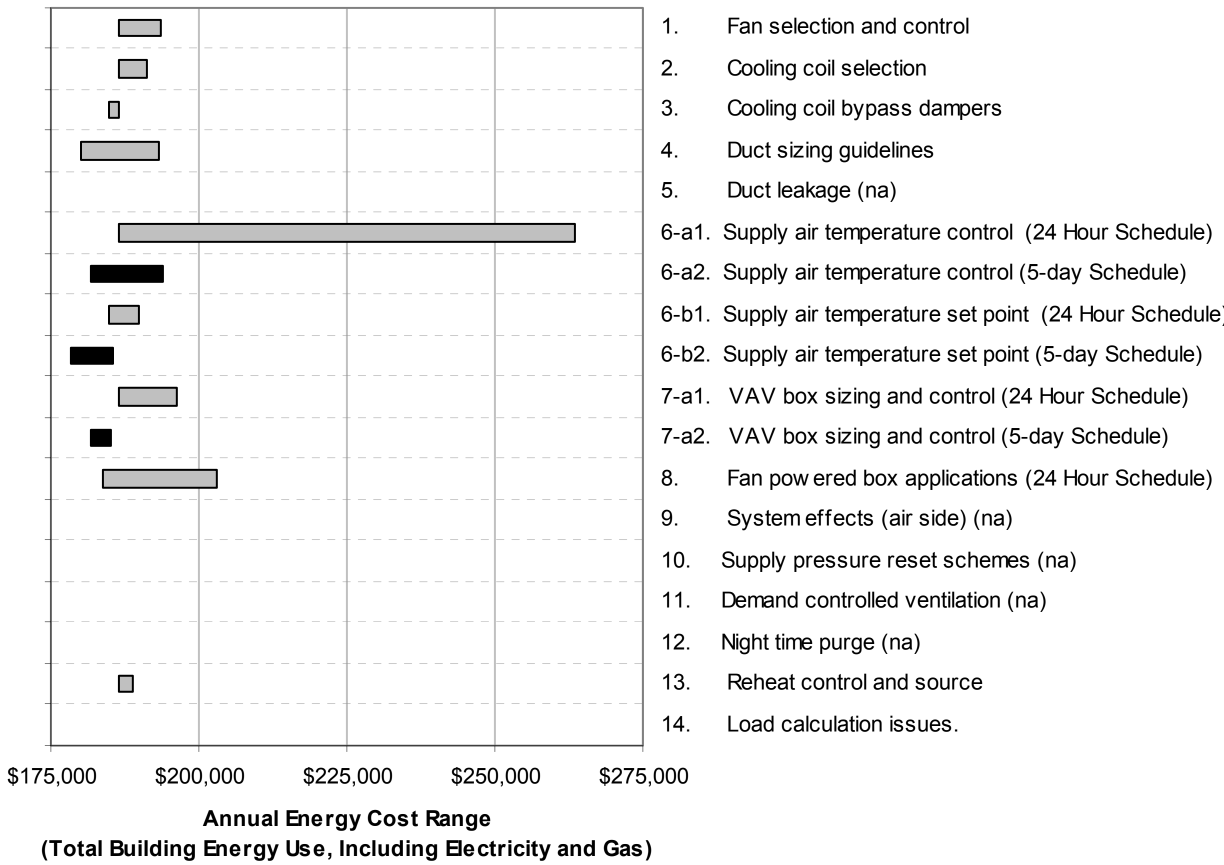

Figure 1 Estimated Range of Energy Cost Impact for each Measure
(Those indicated with "na" have not been evaluated)

Introduction

This document describes the sensitivity analysis based on Site #1, which is currently being monitored. The purpose of this analysis is to make preliminary estimates of the impact of these measures on the building's energy use. This will help in streamlining the monitoring effort in the other buildings being studied. Most of the measures will be evaluated with a preliminary building model using the DOE-2.2 simulation program. Details of the DOE-2.2 input are listed at the end of the report in Appendix B - List of DOE-2 Keywords and Values Used for the Analysis.

1. Fan Selection

1.1 *Guideline Problem Description*

Fan energy is wasted unnecessarily through inappropriate fan selection. Fans are typically selected based on peak airflow at design conditions or may be sized to account for anticipated future conditions.

Less efficient fan types are sometimes chosen to reduce first costs. For example forward-curved fans may be selected instead of airfoil fans.

1.2 *Sensitivity Analysis Goal*

The aim is to use the simulation model to estimate the potential energy impact of changing the fan size and fan type. The information will help determine the appropriate amount of effort in later evaluation and monitoring related to the fan selection measure.

1.3 *Methodology*

In addition to modeling the specific fans actually installed at Site #1 (two 66 in. diameter centrifugal plenum (unhoused) fans with airfoil blades), we chose two other similar fans from the same product line with smaller diameter (60 in. and 49 in.) in addition to a vane-axial type fan. We did not choose a larger diameter alternative because the next larger size, 73 in., was not rated for airflow low enough for this system and would not be a realistic selection.

To represent the performance of each fan in DOE2.2, it was necessary to develop a part-load performance curve for each alternative. This curve provides fan power as a function of airflow. The curve depends on both the fan itself and on the building's air distribution system. The pressure required from the fan will vary with airflow. That requirement is a characteristic of the duct system and is independent of the fan type. Then, each fan has different characteristics with regard to power required to provide a certain airflow at a specific pressure. The curves used by DOE2.2 as a default are shown in Figure 2 and depend only on the type of fan control.

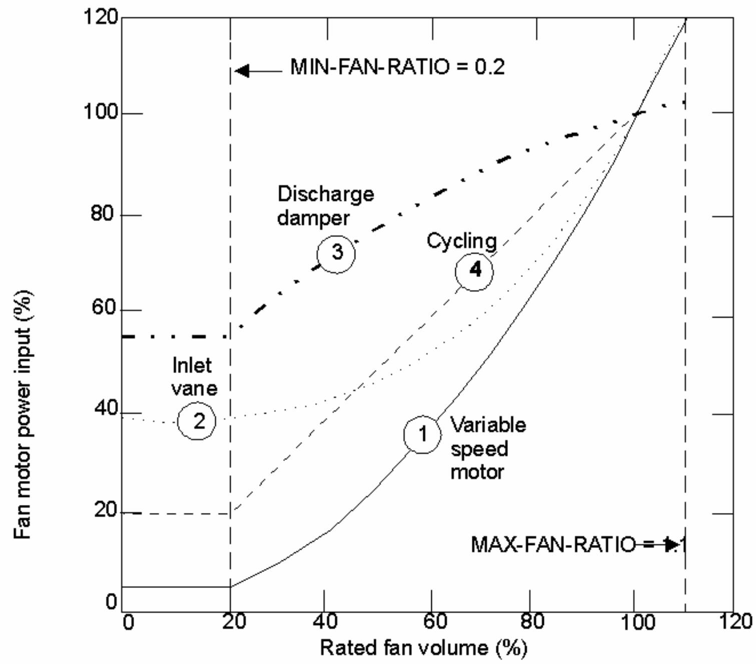

Figure 2: DOE-2 Default Curves
(Curve 1 was used for this analysis)

Development of the custom fan curves follows two steps. First, the monitored static pressure and airflow of the AHU system were plotted as shown in Figure 3. This is the building's "system curve". The monitored data are not a clean curve, so a quadratic curve-fit is used to represent an average system curve. Note that the system was operating at less than 50% of the design flow during this preliminary monitoring period (November through February). The peak measured airflow was about 70,000 cfm at about 2.5 in. w.c. while the design air flow is 145,000 at 4 in. w.c. Since the monitored fan data does not cover the entire range of fan operation, some of the data points in the table have been extrapolated based on the system curve equation.[1] Table 1 shows the estimated average system curve (static pressure as a function of airflow).

The second step requires fan manufacturer's data ("fan curves") that are used to determine fan power at points along the system curve (see Table 4 through Table 7). Those fan power points are plotted and a cubic equation is fit to the data for use in DOE2.2.

The fans simulated for this analysis include the following:

1. DOE-2 default variable speed fan.
2. Existing Fan based on monitored performance data.
3. 660 CPL-A: 66 in. Loren Cook centrifugal fan with backwardly inclined airfoil blades.
4. 600 CPL-A: 60 in. Loren Cook centrifugal fan with backwardly inclined airfoil blades.
5. 490 CPL-A: 49 in. Loren Cook centrifugal fan with backwardly inclined airfoil blades.
6. VAB 54: 54 in. Trane vane axial fan with variable pitch blades.

[1] The actual fan static pressure may actually be greater than shown in Figure 3 because there are backdraft dampers at the inlet to the supply fans that included in the differential SP measurement. Therefore, the "system curve" should probably be shifted slightly higher. This issue was discovered after the sensitivity analysis was completed, but the impact on results should not be too large.

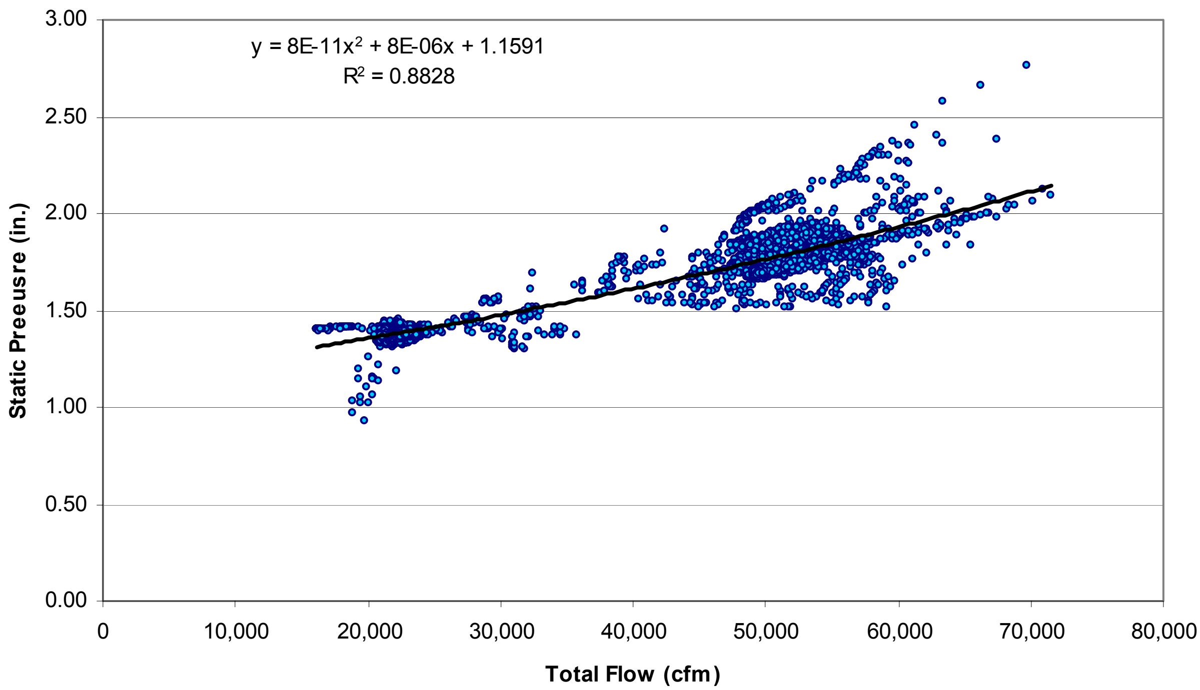

Figure 3: Monitored Supply Fan Static Pressure as a Function of Air Flow (for period November 2001 through February 2002). With Quadratic Curve Fit to Represent Average Building System Curve for Developing DOE2.2 Fan Performance Curves.

Table 1: Average "System Curve" Estimated Based on Monitored Data

Individual Fan Airflow (cfm)	Total System Airflow (cfm)	Pressure Drop (in. WG)
0	0	1.16
10,000	20,000	1.35
15,000	30,000	1.47
20,000	40,000	1.61
25,000	50,000	1.76
30,000	60,000	1.93
35,000	70,000	2.11
40,000	80,000	2.31
45,000	90,000	2.53
50,000	100,000	2.76
55,000	110,000	3.01
60,000	120,000	3.27
65,000	130,000	3.55
70,000	140,000	3.85
75,000	150,000	4.16

System Curve Equation: $y = 8E\text{-}11*(x)^2 + 8E\text{-}06*x + 1.1591$
Where:
y = Pressure Drop
x = Fraction of Peak Airflow

The building (site #1) is served by two Loren Cook fans (660 CPL-A) arranged in parallel, each sized at 72,500 cfm and 4 in. of static pressure (SP). The fans are plenum type, have radial discharge, and are belt driven. They have airfoil with backward inclined blades with 66 in. wheel diameter.

DOE-2 is not capable of simulating two fans operating in parallel, therefore a single representative fan with 145,000 cfm and 4 in. of SP was used for all the simulations.

The performance data and efficiency curves (EIR = f(PLR)) for the selected fans is shown in the following tables. The fan performance curves were derived from the manufacturers' fan performance data, included as an appendix to this report. (See

Appendix A – Fan Properties) The DOE2.2 curve is in the form of a cubic equation, and is shown on the part load efficiency plots for the respective fan. These part load curves along with the mechanical and total fan efficiencies listed in Table 2 were used as inputs to the DOE-2 program.

Table 2: Fan Properties for Simulated Alternatives

Name	Fan Type	Fan Diameter (in.)	Design Power (kW)	Design Mech. Efficiency [2]	Design Total Efficiency [3], [4]
DOE-2 VSD	Centrifugal	NA	55	74%	67%
Monitored	Centrifugal	66	55	64%	58%
660 CPL-A	Centrifugal	66	60	61%	55%
600 CPL-A	Centrifugal	60	67	55%	49%
490 CPL-A	Centrifugal	49	88	42%	37%
VAB 54	Vane Axial	54	74	49%	44%

For the monitored fans described below in Table 3, the power and efficiency are calculated using performance curves derived from monitored air flow, pressure and kW data. Those curves are plotted in Figure 4. The data in the upper half of the air flow range is essentially an extrapolation.

[2] The mechanical efficiency was calculated using the fan equation $n = \frac{cfm * \Delta P}{BHP * 6350}$

[3] The motor efficiency was assumed to be 90% for calculating the overall fan efficiency.

[4] The total efficiency is the overall, combined efficiency of the supply fan and motor at the design flow rate.

Table 3: Partial Load Fan Performance Data Used for Simulation – Monitored Fan 1 & Fan 2

Airflow (cfm)	Pressure Drop (in. WG)	Fan #1 Power (kW)	Fan #1 Power (bhp)[1]	Fan #1 Efficiency	Fan #2 Power (kW)	Fan #2 Power (bhp)[1]	Fan#2 Efficiency
10,000	1.35	7.8	9.4	20%	6.72	8.1	24%
15,000	1.47	10.7	12.9	24%	9.74	11.8	27%
20,000	1.61	13.5	16.3	28%	12.74	15.4	30%
25,000	1.76	16.2	19.5	32%	15.75	19.0	33%
30,000	1.93	19.0	22.9	36%	18.80	22.7	36%
35,000	2.11	21.8	26.4	40%	21.94	26.5	40%
40,000	2.31	24.9	30.1	44%	25.20	30.4	43%
45,000	2.53	28.3	34.2	47%	28.63	34.5	47%
50,000	2.76	32.1	38.7	50%	32.25	38.9	50%
55,000	3.01	36.4	43.9	53%	36.11	43.6	54%
60,000	3.27	41.2	49.7	56%	40.25	48.6	57%
65,000	3.55	46.6	56.2	58%	44.70	53.9	61%
70,000	3.85	52.8	63.7	60%	49.50	59.7	64%
75,000	4.16	59.8	72.2	61%	54.69	66.0	67%

[1] Fan brake horsepower (bhp) calculated from kW assuming 90% motor efficiency

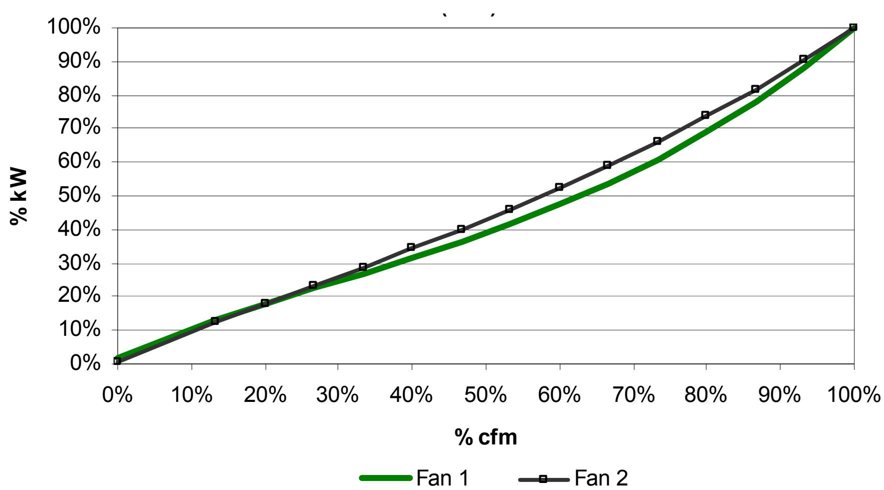

Figure 4: Monitored Fans - EIR =f(PLR) Fan Curves

Table 4: Fan Power at Varying Airflow Conditions Based on Manufacturer's "Fan Curves" – Fan 660 CPL-A (centrifugal, 66 in. diameter, actual installed fan)

Airflow (cfm)	Pressure Drop (in. WG)	Fan Power (BHP)[1]	% Airflow	% Power	Fan Eff.
30,000	1.93	14.6	40%	18%	62%
35,000	2.11	18.0	47%	22%	65%
40,000	2.31	22.1	53%	27%	66%
45,000	2.53	26.4	60%	33%	68%
50,000	2.76	33.3	67%	41%	65%
55,000	3.01	39.8	73%	50%	65%
60,000	3.27	46.3	80%	58%	67%
65,000	3.55	58.0	87%	72%	63%
70,000	3.85	68.5	93%	85%	62%
75,000	4.16	80.4	100%	100%	61%

[1] From manufacturer's fan performance data.

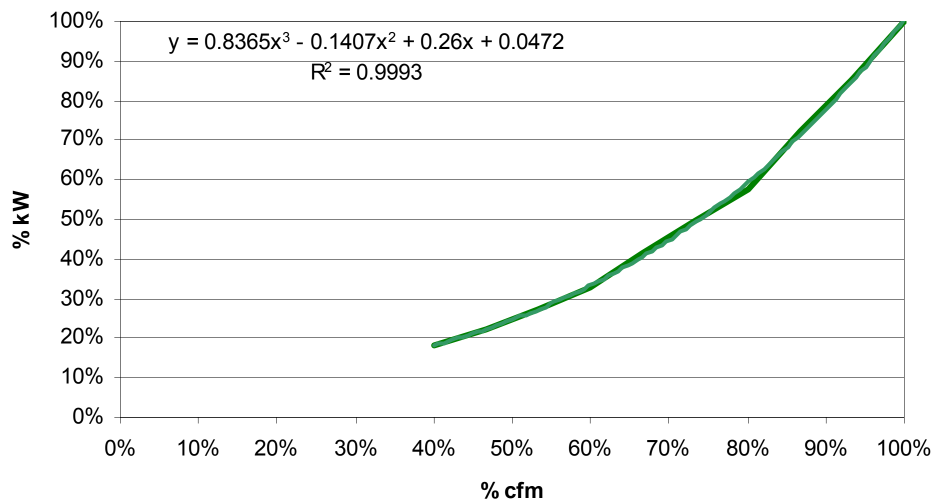

Figure 5: EIR =f(PLR) Fan Curve for 660 CPL-A

Table 5: Fan Power at Varying Airflow Conditions Based on Manufacturer's "Fan Curves" – Fan 600 CPL-A (centrifugal, 60 in. diameter)

Airflow (cfm)	Pressure Drop (in. WG)	Fan Power (BHP) [1]	% Airflow	% Power	Fan Eff.
25,000	1.76	11.0	33%	12%	63%
30,000	1.93	13.7	40%	15%	66%
35,000	2.11	17.7	47%	20%	66%
40,000	2.31	22.5	53%	25%	65%
45,000	2.53	28.2	60%	31%	63%
50,000	2.76	35.4	67%	39%	61%
55,000	3.01	43.8	73%	49%	60%
60,000	3.27	53.2	80%	59%	58%
65,000	3.55	64.0	87%	71%	57%
70,000	3.85	76.2	93%	85%	56%
75,000	4.16	90.0	100%	100%	55%

[1] From manufacturer's fan performance data.

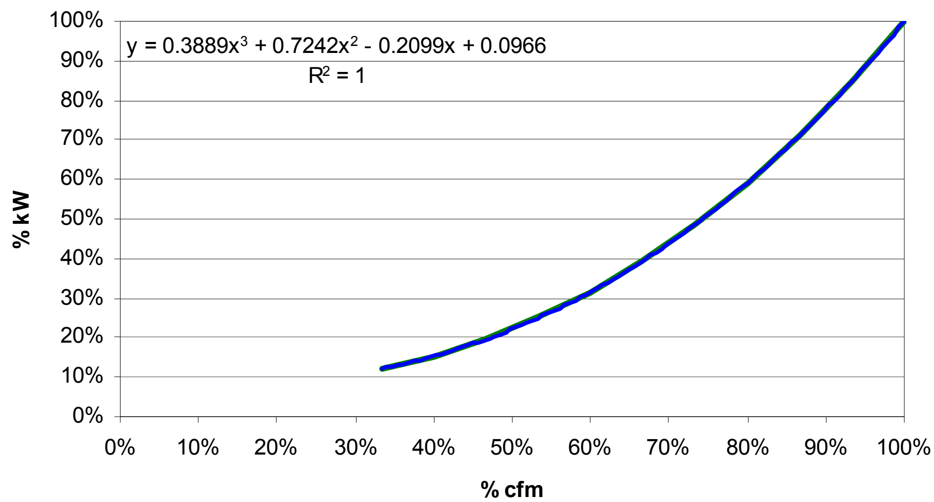

Figure 6: EIR =f(PLR) Fan Curve for 600 CPL-A

Table 6: Fan Power at Varying Airflow Conditions Based on Manufacturer's "Fan Curves" – Fan 490 CPL-A (centrifugal, 49 in. diameter)

Airflow (cfm)	Pressure Drop (in. WG)	Fan Power (BHP) [1]	% Airflow	% Power	Fan. Eff
20,000	1.6	7.8	27%	7%	65%
25,000	1.8	11.3	33%	10%	61%
30,000	1.9	15.6	40%	13%	58%
35,000	2.1	20.8	47%	18%	56%
40,000	2.3	27.2	53%	23%	54%
45,000	2.5	34.8	60%	29%	51%
50,000	2.8	43.9	67%	37%	50%
55,000	3.0	54.7	73%	46%	48%
60,000	3.3	67.5	80%	57%	46%
65,000	3.6	82.3	87%	70%	44%
70,000	3.8	99.1	93%	84%	43%
75,000	4.2	118	100%	100%	42%

[1] From manufacturer's fan performance data.

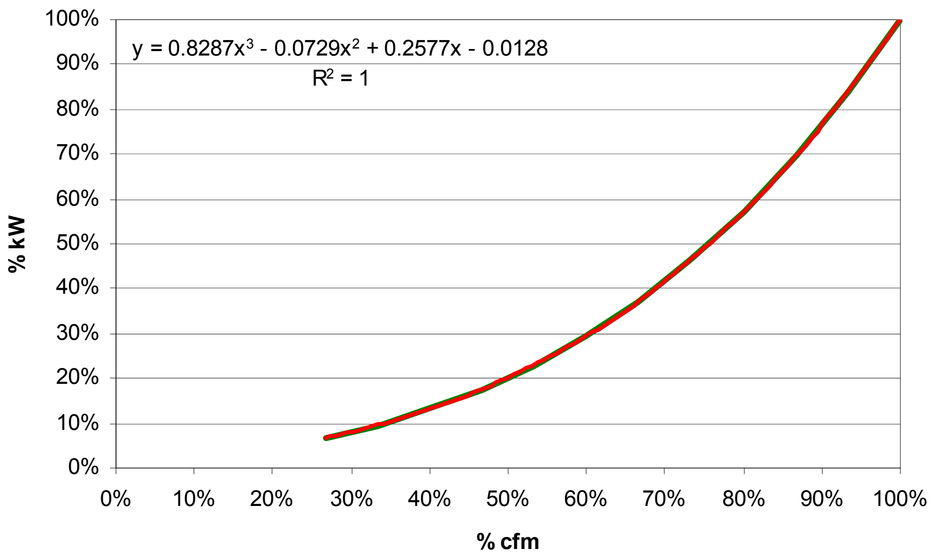

Figure 7: EIR =f(PLR) Fan Curve for 490 CPL-A

Table 7: Fan Power at Varying Airflow Conditions Based on Manufacturer's "Fan Curves" – Fan VAB 54 (Vane Axial, 54 in. diameter)

Airflow (cfm)	Pressure Drop (in. WG)	Fan Power (BHP) [1]	% Airflow	% Power	Fan Eff.
30,000	1.93	14.64	0.40	0.15	62%
35,000	2.11	18.97	0.47	0.19	61%
40,000	2.31	24.22	0.53	0.24	60%
45,000	2.53	30.57	0.60	0.31	59%
50,000	2.76	38.29	0.67	0.38	57%
55,000	3.01	47.21	0.73	0.47	55%
60,000	3.27	57.69	0.80	0.58	54%
65,000	3.55	69.99	0.87	0.70	52%
70,000	3.85	83.76	0.93	0.84	51%
75,000	4.16	99.47	1.00	1.00	49%

[1] From manufacturer's fan performance data.

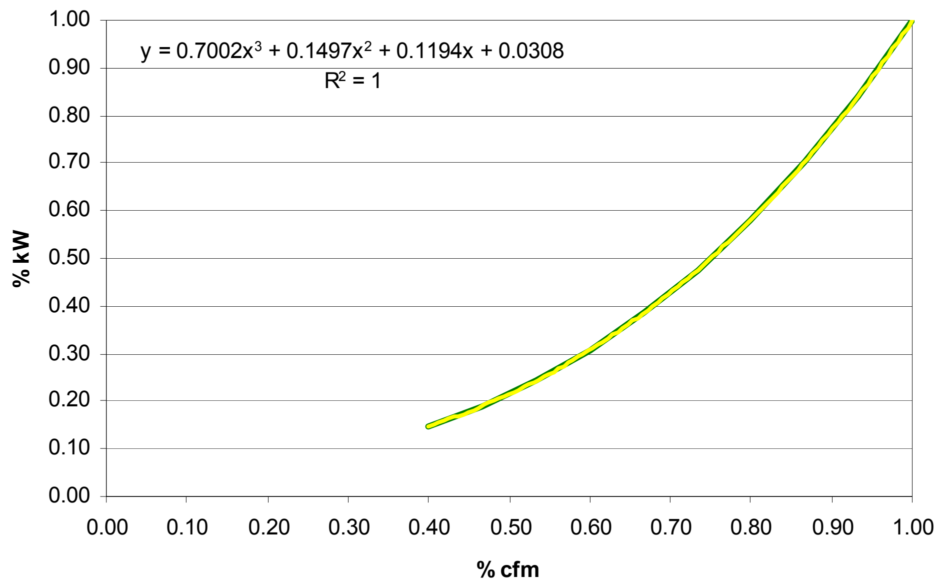

Figure 8: EIR =f(PLR) Fan Curve for VAB 54

Figure 9 shows the variation in fan power with airflow for these fans. The fan curves calculated from monitored data are conspicuous by their significantly lower part load efficiency (higher power). And as shown later in the results section this leads to higher energy consumption because the system usually operates at partial flow. More analysis and monitored data covering a wider operating range will be necessary to confirm whether these curves are an accurate result.

Figure 9 also shows that the DOE2.2 default fan curve and default efficiency result in better performance than predicted by manufacturers data for the selected fans.

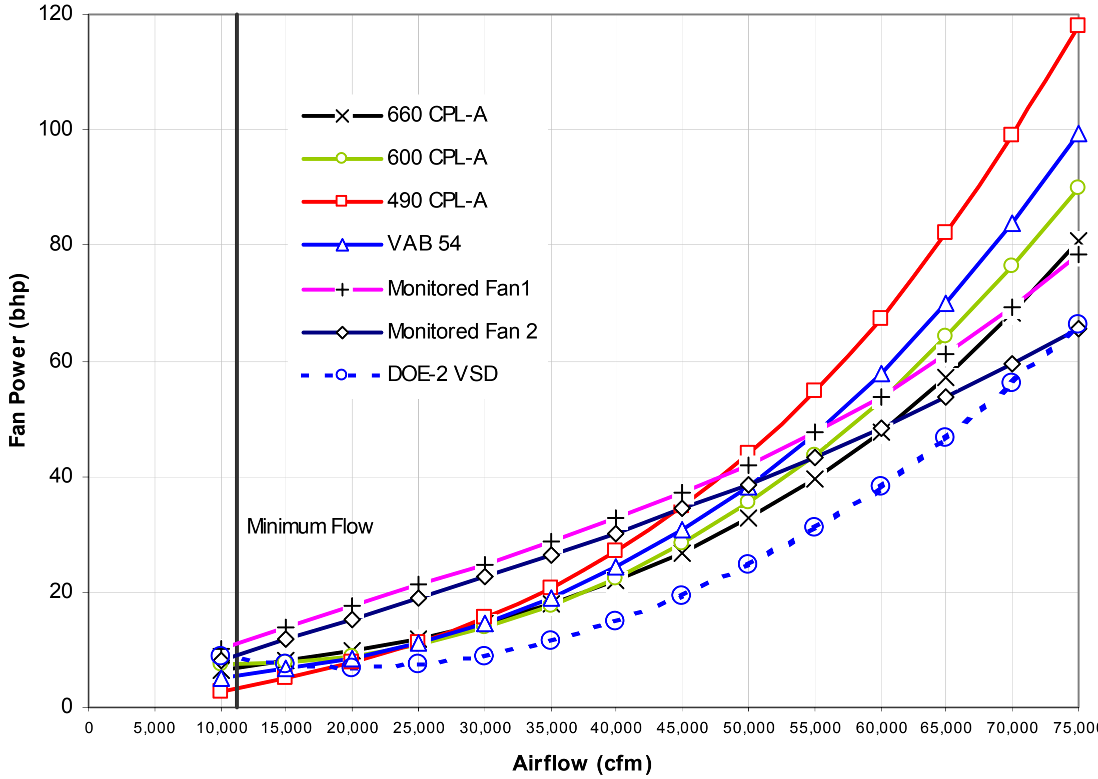

Figure 9: Fan Power vs. Airflow Comparison

1.4 *Results*

The simulation results show that most of the time the fan runs at low part loads (See Table 8). The performance of the fan at lower part loads thus has a significant impact on the HVAC energy use of the building.

Table 8: Base Case Supply Fan - Number of Hours at Each Part Load

Part Load	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	TOTAL
No. of Hours	0	0	3413	1370	2435	1542	0	0	0	0	8760

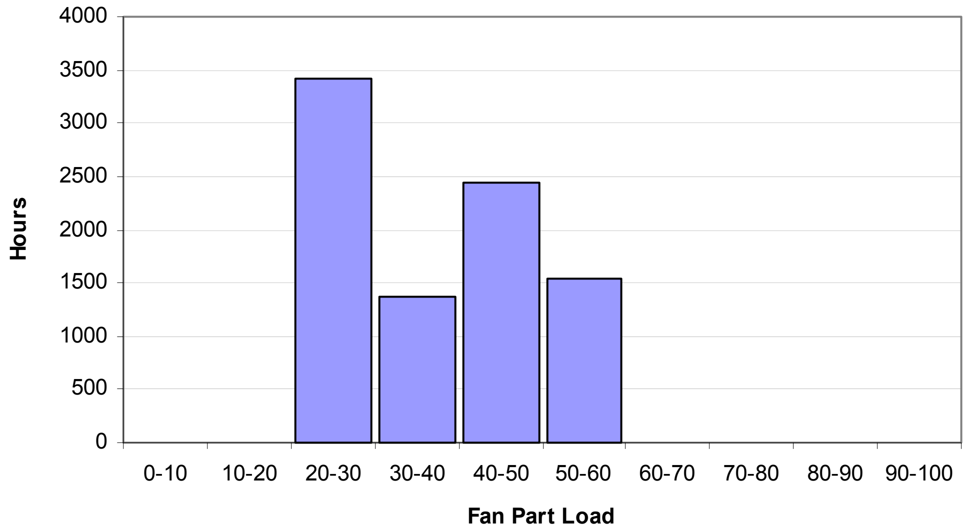

Figure 10: Base Case Supply Fan - Number of Hours at Each Part Load

Table 9 shows the annual HVAC energy use listed by end use for the whole building for each alternative fan selection. The impact of fan selection is not limited to fan energy only. As the fan energy use increases, additional fan heat is dissipated to the supply air stream, increasing the cooling energy end use, which in turn results in higher tower and pump energy.

The DOE-2 default VSD fan has a significantly lower fan energy use because of higher default efficiency (See Table 2 for details). This results in lower cooling energy use, and higher heating fuel use due to less heat being transferred to the supply air from the fan. The monitored fan has the worst performance with 74% more energy use compared to the base case. This is due to poor part load performance as shown by the monitored data.

The results reflect the fact that larger diameter fan wheels are more efficient at higher airflow but slightly less efficient at very low flow. The 60 in. fan shows slightly lower total fan energy than the 66 in. fan, because the part load performance of the smaller fan at minimum flow conditions is slightly better (See Figure 9). But the larger fan results in slightly lower total energy because less cooling is necessary (because the fan is more efficient at higher airflow). Both fan and cooling energy increase with the 49 in. fan and the 54 in. vane axial fan.

Table 9: Annual HVAC Energy Use by End use (Fan Selection and Control)

	Electricity (kWh)										Fuel (MBtu)	
	Cooling	%	Heat Reject	%	Pumps & Aux	%	Fans	%	Total	%	Heating	%
DOE-2 VSD	253,353	98%	28,000	96%	219,873	100%	168,480	72%	1,841,559	96%	314.2	105%
Monitored	270,529	105%	31,632	109%	220,309	100%	409,191	174%	2,103,513	110%	264.2	89%
660 CPL-A (Base Case)	258,100	--	29,018		219,983		234,812		1,913,766	--	298.0	--
600 CPL-A	258,812	100%	29,218	101%	220,001	100%	234,623	100%	1,914,506	100%	300.8	101%
490 CPL-A	262,869	102%	30,091	104%	220,094	100%	271,320	116%	1,956,225	102%	297.5	100%
VAB 54	260,346	101%	29,547	102%	220,032	100%	249,851	106%	1,931,629	101%	298.7	100%

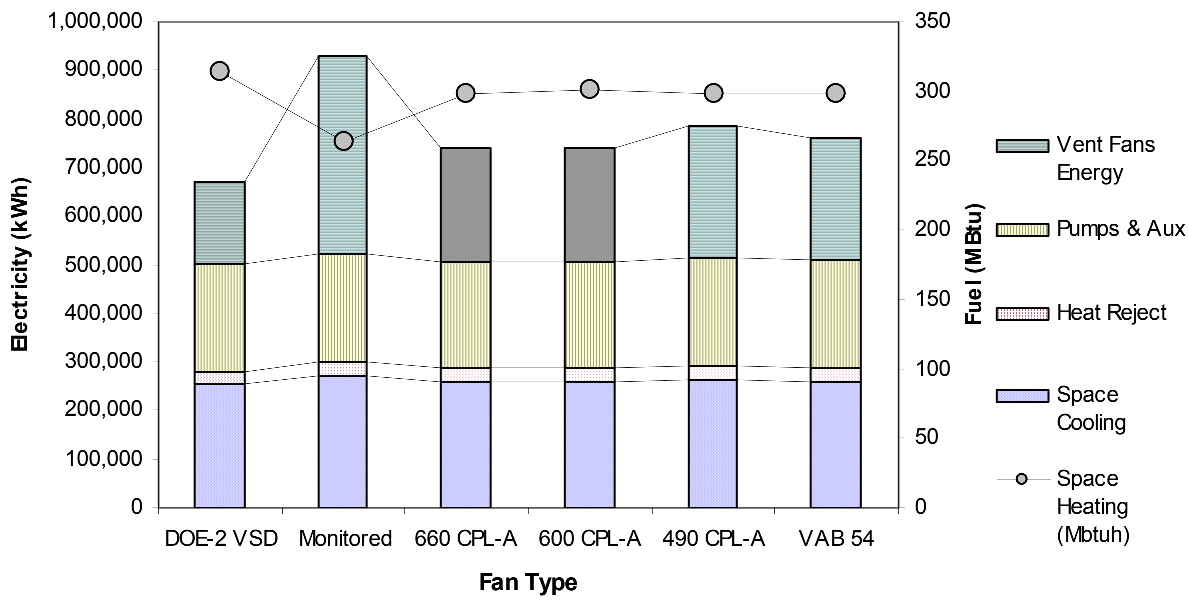

Figure 11: HVAC Energy Use Comparison (Fan Selection and Control)

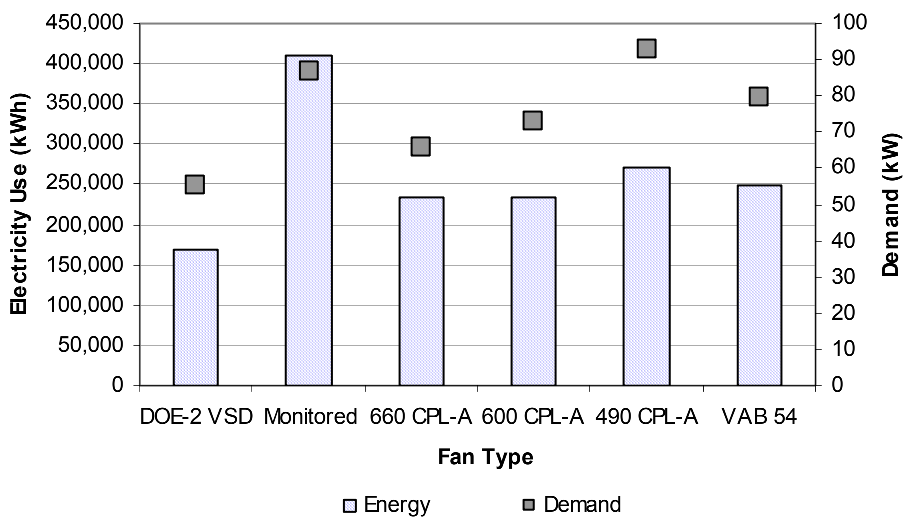

Figure 12: Fan Energy and Demand (Fan Selection and Control)

Table 10: Utility Cost Comparison (Fan Selection and Control)

Fan Type	Electricity Energy	Electricity Demand	Electricity Total	Natural Gas Total	Total Utility	% Diff.
DOE-2 VSD	$112,800	$63,505	$178,406	$2,084	$180,490	97%
Monitored	$128,255	$69,831	$200,186	$1,769	$201,955	108%
660 CPL-A (Base Case)	$117,102	$65,467	$184,669	$1,982	$186,651	--
600 CPL-A	$117,316	$66,411	$185,828	$2,000	$187,828	101%
490 CPL-A	$120,128	$69,292	$191,519	$1,979	$193,498	104%
VAB 54	$118,437	$67,401	$187,938	$1,987	$189,925	102%

1.5 *Observations*

The fan appears to be well sized for this building. It is larger than necessary according to simulation results, but that improves the efficiency. As mentioned earlier, increasing the fan diameter to 73 in. would probably not be feasible because it might not be able to handle the minimum flow.

Reducing the fan size from 66 in. to 60 in. has little impact on overall fan energy but increases total utility cost by about 1%.

Reducing the fan size from 66 to 49 inches increases fan energy by about 16% and total utility costs by about 4%.

This building actually runs 24 hours per day, with partial occupancy in the evening, and that is how it is modeled for this fan analysis. Therefore, there are many hours of low-load operation, and that favors the smaller fans. If the building operated only for normal business hours, then the larger fan might show better relative overall performance.

This analysis does not take into account the acoustical performance of each fan. Noisier fans (generally smaller fans that need to run faster) will produce more noise. Therefore, more restrictive sound traps might be required for equal acoustical performance, and the pressure loss would increase. Since we have not adjusted the system curve to account for acoustics, we may be underestimating the relative benefit of the larger (quieter) fans.

Simulation results show that the impact of fan selection on energy cost is modest. Within a small range of sizes it doesn’t make too much difference. But the results also show a large difference between simulations based on manufacturers’ data and the simulations using either DOE2.2 defaults or curves based on monitored data. The DOE2.2 defaults lead to 28% lower fan energy and the results derived from monitored data are 74% higher than the base case (manufacturer’s data for the actual installed 66 in. fan).

1.6 *Conclusions*

As far as the guidelines are concerned, these results suggest it may be possible to place low to moderate emphasis on the subject of fan sizing.

But these results also suggest that more investigation is warranted regarding absolute fan system performance. The absolute (rather than relative) energy consumption for air distribution is important when evaluating optimal integrated design. It appears that typical simulation assumptions don’t reflect reality in terms of part load efficiency, which affects optimal integrated design choices. If fans do not operate as efficiently as manufacturers claim at low loads, then design strategies that aim to reduce airflow (at the expense of chiller energy) may not be as effective as simulations would predict. This topic will require more analysis with complete monitoring results.

Therefore, it appears to be important to get an accurate picture of actual fan performance from the remaining monitoring sites. The main purpose of the data is to improve the accuracy of fan power calculations for evaluation of integrated design tradeoffs. These data include airflow, differential static pressure and fan power.

2. Cooling Coil Selection

2.1 *Guideline Problem Description*

Cooling coils are typically selected based on peak load and airflow conditions and to minimize equipment cost. The results can be excess fan pressure, low CHW delta T, excess pump energy, and reduced chiller efficiency

2.2 *Sensitivity Analysis Goal*

The objective of the analysis was to evaluate the impact of cooling coil size and design on the building's energy use.

2.3 *Methodology*

Alternative coil selections were evaluated using DOE-2.2 simulations. DOE-2.2 was used for this evaluation, because it accounts for the impact on both the airside and the chilled water loop. The sensitivity analysis simulations use the baseline fan performance data described earlier in the fan-selection discussion. Coil characteristics such as air pressure loss and chilled water pressure loss are determined from manufacturers' coil specification software. The simulation estimates the fan energy and pump energy impacts for different coil selections.

The impact on the chilled water loop is modeled by entering the coil head (pressure loss) and delta-T at design conditions. The following curves modify the cooling coil's performance at off-design conditions, and are required for the DOE-2 simulation.

1. Total capacity as a function of entering air temperature
2. Total capacity as a function of entering water temperature
3. Sensible capacity as a function of entering air temperature
4. Total capacity as a function of supply airflow
5. Total capacity as a function of supply chilled water flow
6. Bypass factor as a function of entering air temperature
7. Bypass factor as a function of airflow
8. Bypass factor as a function of part load

Due to limited time it was not possible to develop these curves for every coil type that was evaluated, therefore default DOE-2 curves were used for this analysis.

The base case was the existing coil specified for the system. The properties of cooling coils selected for this analysis are shown in Table 11. All the coils were selected to maintain the same cooling capacity at the same entering air and water temperatures and airflow as the base case coils. The selection procedure was also constrained to maintain the leaving air dry bulb and wet bulb temperatures close to those for the base case coil. The selected coils vary in their construction, number of rows, fin spacing, air and fluid pressure drops, and the leaving fluid temperature. These cooling coil properties were modified in the simulation model for each alternative. The supply fan static pressure was also adjusted in each case to account for the different pressure drop across the coils. The impact of the coils on the supply fan part load curve was analyzed for each coil, but the difference was insignificant for the range of coils selected. Therefore the base case (660 CPL-A) fan curve was used for all the simulations.

Table 11: Cooling Coil Data

Coil Type	Number of Coils	Rows	Fin Spacing (Fins/ft)	Airflow/Coil (cfm)	Total Cooling Capacity/Coil (Mbtu)	Sensible Capacity/Coil (Mbtu)	Total Cooling Capacity (Mbtu)	Sensible Capacity (Mbtu)	Leaving Drybulb (ºF)	Leaving Wetbulb (ºF)	Air Pressure Drop (in. WG)	Face Velocity (ft./min)	Fluid Pressure Drop (in. WG)	Standard Flow Rate (gpm)
Base Case (Existing Coil)	3	6	120	48,300	1,585	1,446	4,755	4,338	50.90	49.70	0.70	767	13.20	202
Coil 1	3	6	107	48,300	1,347	1,303	4,042	3,908	50.90	50.36	1.68	767	31.94	192
Coil 2	6	4	123	24,200	677	653	4,062	3,917	50.90	50.33	0.38	384	6.75	96
Coil 3	6	4	108	24,200	692	653	4,152	3,917	50.90	50.08	0.36	384	17.34	99
Coil 4	8	4	96	18,125	527	491	4,217	3,929	50.79	49.89	0.21	288	10.79	75
Coil 5	8	4	109	18,125	511	489	4,085	3,911	50.90	50.25	0.22	288	4.05	73

Common Coil Properties:	
Finned Length	168 in.
Nominal Coil Height	54 in.
Entering Drybulb	75.5 °F
Entering Wetbulb	60.5 °F
Entering Water	42.0 °F
Leaving Water	56.0 °F
Coil Face Area	63 (for total face area multiply this value by the number of coils listed in the table above)
Total Design Airflow	145,000 cfm

2.4 *Results*

The results of the cooling coil analysis are shown in Table 12 and Table 13. They indicate that the coil air pressure loss accounts for most of the energy impact. Coil 1 has an air pressure drop of 1.68 in. w.c. as compared to 0.70 in. w.c. for the base case coil and only 0.22 in. w.c. for the largest coil. (Note that the pressure loss for coil 1 is probably greater than would normally occur, because the face air velocity is over 700 fpm, which is a bit higher than typical designs that aim for a maximum of 550 to 600 fpm to prevent condensation from blowing off the coils). Higher pressure loss leads to higher fan, cooling, heat rejection, and pump energy usage. Coil 4 with the lowest air and fluid pressure drops, results in the best performance in terms of overall building utility cost. Overall the coil selection has a 1-2% impact on the total building utility cost.

Table 12: Annual Energy Use by End use (Cooling Coil Selection)

	Electricity (kWh)										Fuel (MBtu)	
	Cooling	% Diff	Heat Reject	% Diff	Pumps & Aux	% Diff	Fans	% Diff	Total	% Diff	Heating	% Diff
Base case	258,100	--	29,018	--	219,983	--	234,812	--	1,913,766	--	298.0	--
Coil 1	260,827	101%	29,810	103%	219,676	100%	277,465	118%	1,959,631	102%	290.3	97%
Coil 2	258,090	100%	29,122	100%	219,943	100%	237,641	101%	1,916,647	100%	297.6	100%
Coil 3	257,817	100%	29,041	100%	219,706	100%	236,347	101%	1,914,764	100%	297.7	100%
Coil 4	257,129	100%	28,882	100%	219,840	100%	226,620	97%	1,904,323	100%	299.3	100%
Coil 5	257,242	100%	28,895	100%	220,025	100%	227,268	97%	1,905,283	100%	299.2	100%

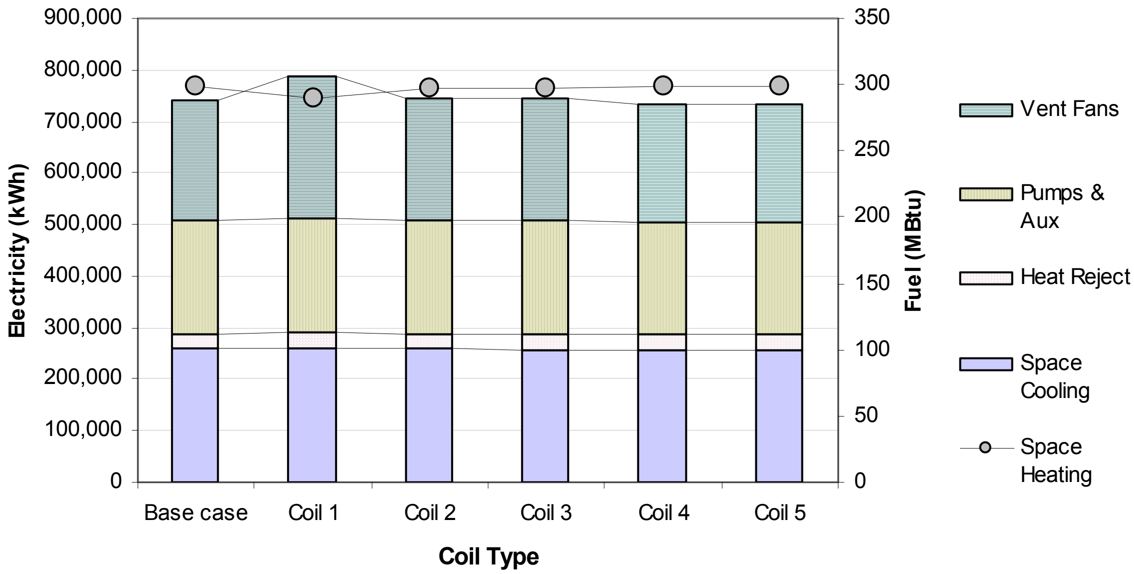

Figure 13: Annual HVAC Energy Use Comparison (Cooling Coil Selection)

Table 13: Utility Cost Comparison (Cooling Coil Selection)

Coil Type	Electricity Energy	Electricity Demand	Electricity Total	Natural Gas Total	Total Utility	% Diff.
Base case	$117,102	$65,467	$184,669	$1,982	$186,651	--
Coil 1	$119,912	$67,247	$189,259	$1,934	$191,193	102%
Coil 2	$117,275	$65,555	$184,930	$1,980	$186,910	100%
Coil 3	$117,163	$65,504	$184,767	$1,981	$186,748	100%
Coil 4	$116,523	$65,091	$183,714	$1,990	$185,704	99%
Coil 5	$116,579	$65,115	$183,794	$1,990	$185,784	100%

2.5 *Observations*

Fan energy varies by about 20% over the range of coil selections evaluated here, while pump energy varies relatively little. Cooling coil sizing has a significant impact on fan energy but only a modest impact on overall HVAC energy.

2.6 *Conclusions*

The guidelines regarding coil selection can probably be fairly simple because the energy impact is fairly well understood.

Current monitoring plans do not include measurements of water pressure or air pressure drop across the cooling coils. Due to the modest impacts, the lack of these data are not expected to be a problem. We are, however, performing one time static pressure profile measurements of several sites, and those measurements will provide spot a measurement of air pressure loss through the coil. This measurement will be useful for verifying expected values based on manufacturer data.

3. Cooling Coil Bypass Dampers

3.1 *Guideline Problem Description*

Fan energy is wasted during periods when the cooling coil valve is shut (no CHW flow; a significant number of hours in systems with outdoor air economizers) and air is still flowing through the cooling coil. Air pressure loss would be reduced if a bypass damper allowed the air to flow past the coils through a path with lower pressure loss.

3.2 *Sensitivity Analysis Goal*

The goal is to estimate the energy impact of cooling coil bypass dampers.

3.3 *Methodology*

This measure was evaluated by running the simulation model with and without coil air pressure loss. Whenever the system had no cooling load, the bypass damper was assumed to be 100% open, bypassing the cooling coil, otherwise the dampers were assumed to be closed whenever cooling coil was operating. Hourly fan energy and cooling coil loads were simulated for each case. The result was calculated by combining the hourly results from the two runs so that the no coil pressure drop was modeled whenever the cooling coil load was present.

3.4 *Results*

Energy cost results are not directly available from the simulation because the results of two runs are combined. The total energy cost for the “No Bypass” case is equal to the baseline cost $186,651. For the “Cooling Coil Bypass” case was calculated to be $184,904 based on an average electricity rate of $0.0965/kWh.

Table 14: Annual Energy Use by End use (Cooling Coil Bypass Dampers)

	Electricity (kWh)									
	Cooling	% Diff	Heat Reject	% Diff	Pumps & Aux	% Diff	Fans	% Diff	Total	% Diff
No Bypass	258,100	100%	29,018	100%	219,983	100%	234,812	108%	1,913,766	101%
Cooling Coil Bypass	257,835	100%	29,017	100%	219,952	100%	217,005	100%	1,895,664	100%

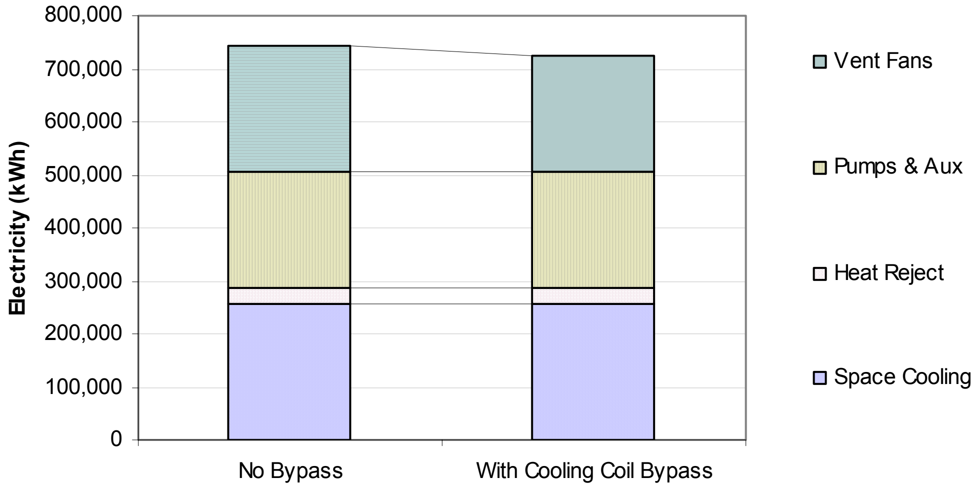

Figure 14: Annual HVAC Energy Use Comparison (Cooling Coil Bypass Dampers)

3.5 *Observations*

The bypass dampers reduce fan energy by about 8% in this model. Savings would probably be less in warmer climates and higher in cooler climates. These results are for San Jose, California.

3.6 *Conclusions*

The fan energy impact is not huge but it is significant, and this measure is worth addressing in the guidelines if it is shown to be cost effective in further analysis. The analysis will be relatively straightforward.

4. Duct Sizing

4.1 *Guideline Problem Description*

Fan energy is wasted due to air pressure loss in small ducts. Due to equipment initial cost considerations, ducts are often smaller than the optimal life cycle cost size.

4.2 *Sensitivity Analysis Goal*

Estimate the range of energy impact for measures that affect duct pressure loss.

4.3 *Methodology*

Potential savings for a range of possible duct designs are calculated by varying the static pressure across the fan in the simulation model. No attempt has been made to evaluate specific duct design options, so it is not clear if these assumptions cover all the possible static pressure values that are attainable. The actual design value for this building was about 4.0 in. WG and was used as the base case. The fan static pressure was varied from 3 to 5 in. w.c. in 0.5 in. increments.

4.4 *Results*

Figure 15 shows the changes in fan and total system energy use as the system static pressure changes due to varying duct sizes. The fan energy and demand use change by 25% for a 1 in. WG change in the total system static pressure (See Figure 16). This translates into a 4% change in the total building utility cost (See Table 16).

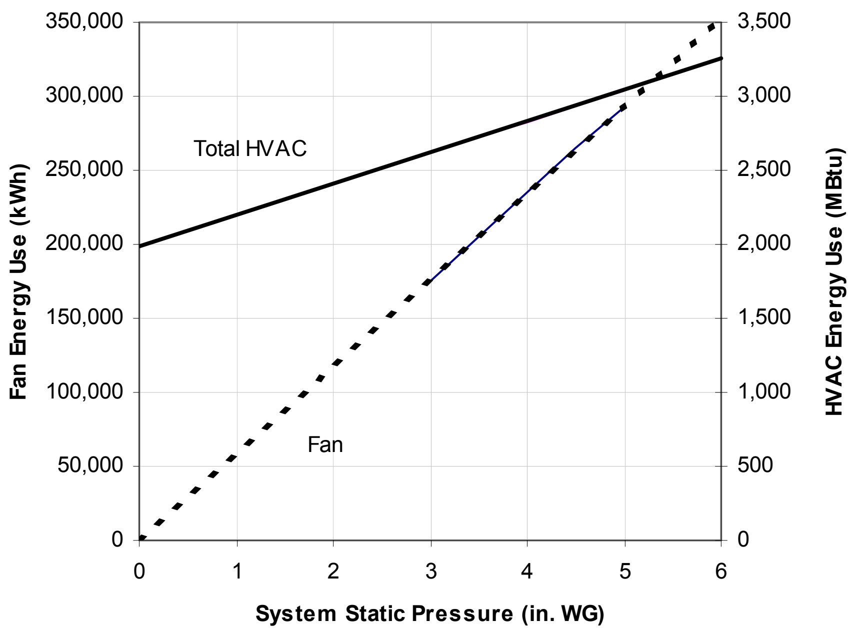

Figure 15: HVAC and Fan Energy Use with Varying System Static Pressure

Table 15: Annual Energy Use by End use (Duct Sizing)

	Electricity (kWh)										Fuel (MBtu)	
Fan S.P.	Cooling	% Diff	Heat Reject	% Diff	Pumps & Aux	% Diff	Fans	% Diff	Total	% Diff	Heating	% Diff
3.0	253,245	98%	27,955	96%	219,870	100%	175,894	75%	1,848,816	97%	310.8	104%
3.5	255,649	99%	28,491	98%	219,921	100%	205,336	87%	1,881,249	98%	304.1	102%
4.0	258,100	--	29,018	--	219,983	--	234,812	--	1,913,766	--	298.0	--
4.5	260,564	101%	29,595	102%	220,044	100%	264,341	113%	1,946,395	102%	292.6	98%
5.0	262,972	102%	30,119	104%	220,095	100%	293,853	125%	1,978,891	103%	286.9	96%

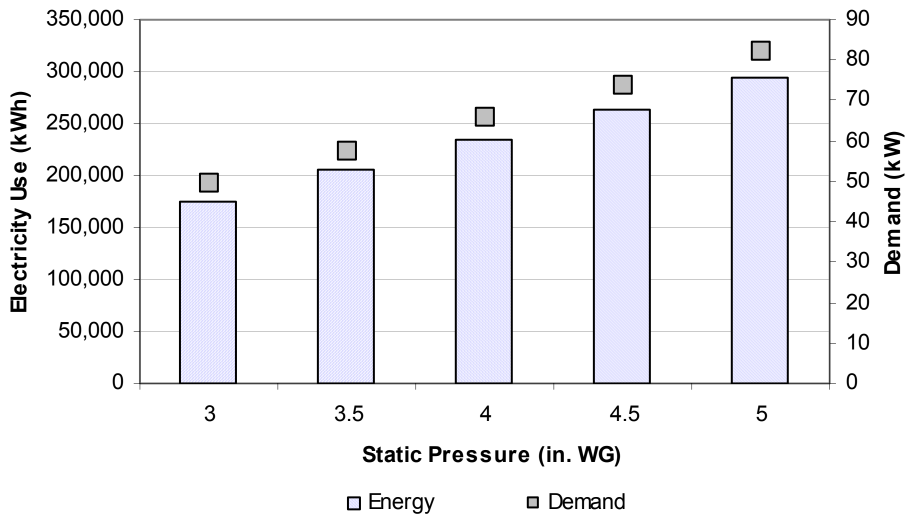

Figure 16: Annual Fan Energy and Demand

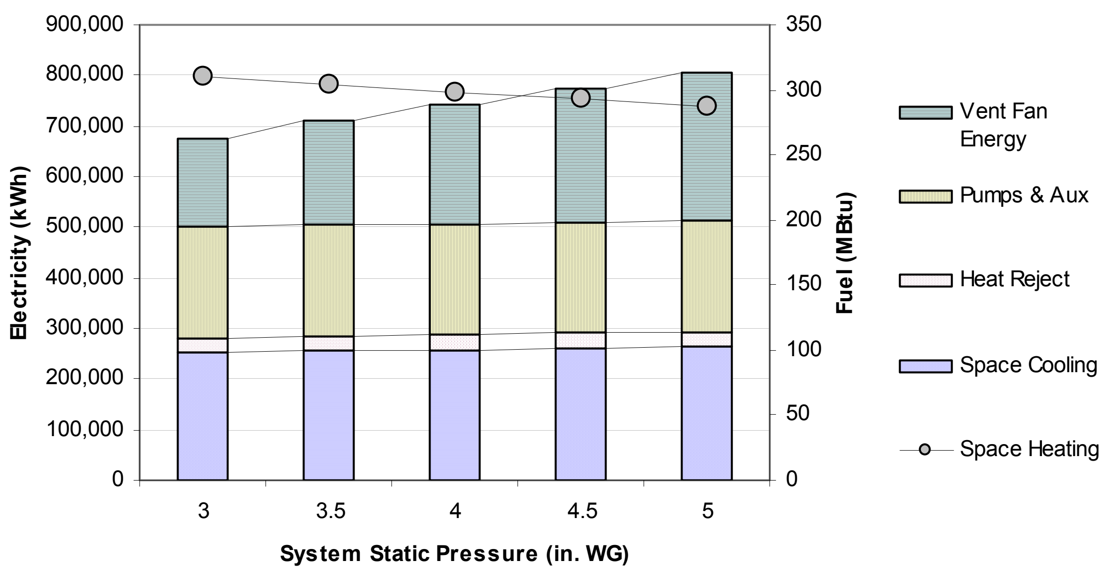

Figure 17: Annual HVAC Energy Use Comparison (Duct Sizing)

Table 16: Utility Cost Comparison (Duct Sizing)

Fan Static (in. WG)	Electricity Energy	Electricity Demand	Electricity Total	Natural Gas Total	Total Utility	% Diff.
3.0	$113,121	$62,947	$178,168	$2,063	$180,231	97%
3.5	$115,110	$64,193	$181,403	$2,020	$183,423	98%
4.0	$117,102	$65,467	$184,669	$1,982	$186,651	--
4.5	$119,101	$66,743	$187,943	$1,948	$189,891	102%
5.0	$121,092	$68,024	$191,217	$1,912	$193,129	103%

4.5 *Observations*

In the simulation model, fan energy increases by 25% if the pressure at design conditions increases from 4 in. to 5 in., and, of course, it decreases by 25% if pressure is reduced from 4 in. to 3 in.

The value of 3 in. may be attainable, but would probably require more than just larger ducts. It would require attention to all aspects of air distribution design, especially transitions and turns in the ductwork. Use of sound traps and backdraft dampers also have an impact.

4.6 *Conclusions*

Duct sizing, or more accurately “duct design”, is an important topic with large potential energy impact. Therefore, the topic deserves significant attention in the guidelines. But there are many duct design guides that have been published, so it will be best to focus on specific elements of design that are not currently covered. Many of the lessons regarding duct design will probably come from the static pressure profile measurements that are being performed to identify system effects issues. The potential impact on fan energy indicates that the pressure profiles are an important measurement.

5. Duct Leakage

Duct leakage will not be a subject of study, partly because the impact of leakage is very difficult to measure accurately and because the subject is being addressed in one of LBNL’s PIER research elements. If LBNL’s results show a significant impact from sealing ducts in large commercial systems, then the topic will be added to our guidelines. The guideline content may be relatively simple, while the research to determine the impact of leakage is difficult.

6. Supply Air Temperature Set Point and Control

6.1 *Guideline Problem Description*

Sub optimal supply air temperature control results in increased overall energy consumption (sum of fan energy, chiller energy, pump energy and reheat energy). A set point that is too low causes excess cooling and reheat energy. A set point that is too high leads to excess fan energy because more airflow is required.

There are two common problems: 1) specifying an optimal reset method and 2) getting the specified reset method actually implemented and maintained.

In some cases temperature reset schemes may not be successful due to presence of problem zones. For example, undersized zones (low airflow) might always require low air temperature while the rest of the zones would be satisfied with higher temperatures.

6.2 *Sensitivity Analysis Goal*

This analysis was done to answer the following two questions:

1. What is the magnitude of the energy impact for different supply air temperature (SAT) be reset schemes?
2. What is the energy impact of using different design supply air temperature when selecting and sizing HVAC equipment?

6.3 *Methodology*

To answer the first question, three alternatives were simulated by controlling the supply air temperature in three different ways:

1. Constant supply air temperature (No Reset)
2. Supply air temperature reset based on the warmest zone
3. Reset based on the outside air temperature (OAT)

In the first case the supply air temperature was constant, in the second case it was varied based on the temperature of the warmest zone being served by the system, and in the third case the supply air temperature was varied based on the outside air temperature. Figure 18 shows the reset temperatures used for the OAT reset option.

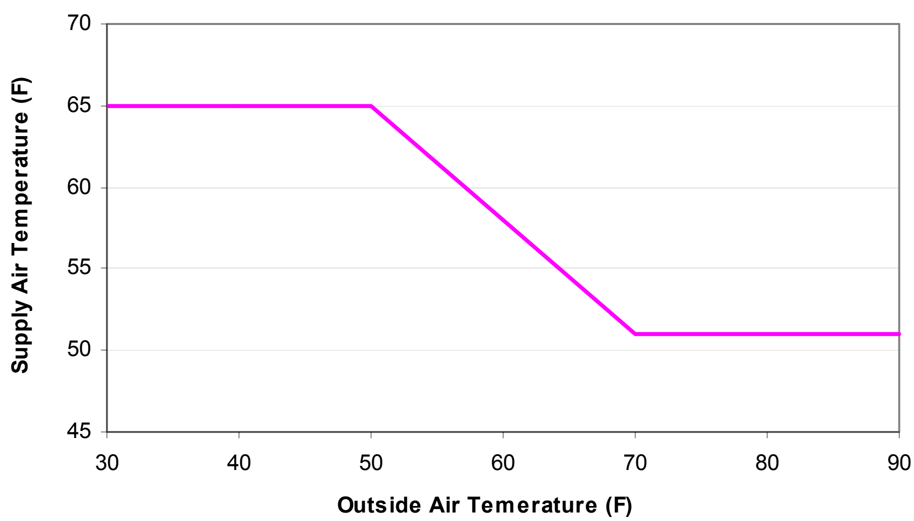

Figure 18: Outside vs. Supply Air Temperatures for OA Based Reset Control

There are three options for resetting the supply air temperature in DOE-2.2:

- Airflow First: Airflow and fan energy are reduced before the supply temperature is reset. This approach minimizes fan energy at the expense of cooling loads.
- Temperature First: The reverse of Airflow First, above: the supply temperature is reset prior to any reduction in airflow. This approach minimizes cooling loads at the expense of fan energy

- Simultaneous: The supply temperature is reset simultaneously with a reduction in airflow. This is a compromise between the two other strategies.

To answer the second question, seven alternative cases were simulated; each with a different cooling supply air temperature and corresponding chilled water supply temperature. The supply air temperature was varied from 45 to 58 F with the corresponding chilled water temperature varying from 36 to 49 F. Since the impact of these measures vary depending on the supply air temperature reset strategy selected, the simulations were run for all four scenarios; no reset, resetting temperature first, resetting airflow first, and resetting airflow and temperature simultaneously.

The impact of these measures also varies based on the fan's operating schedule. The base case building operates on a 24-hour schedule[5], therefore another set of runs with a 5-day office schedule was also analyzed for this measure.

Table 17: Cooling Coil Parameters Selected for Simulating the Impact of Using Varying Supply Air and Chilled Water Temperature Design Values

Supply Air Temperature (F)	Chilled Water Supply Temperature (F)	Total Airflow (cfm)	Air Pressure Drop (in. WG)	CHW Pressure Drop (in. WG)	Chilled Water Flow (gpm)	Sensible Cooling Capacity/Coil (KBtuh)	Total Cooling Capacity/Coil(KBtuh)	Sensible Cooling Capacity (KBtuh)	Total Cooling Capacity (KBtuh)	Chilled Water Delta T (F)
45	36	116475	0.48	30.10	136.2	649.2	815.5	3895.2	4893.0	12.0
47	38	124649	0.53	26.78	128.0	649.2	781.2	3895.2	4687.2	12.2
49	40	134057	0.58	21.94	115.0	649.2	738.7	3895.2	4432.2	12.8
51*	42	145000	0.64	16.50	98.5	650.9	689.5	3905.4	4137.0	14.0
53	44	157889	0.68	14.08	90.5	649.7	649.7	3898.2	3898.2	14.4
55	46	173293	0.80	15.23	94.8	649.7	649.7	3898.2	3898.2	13.7
58	49	203000	1.05	17.39	102.6	649.7	649.7	3898.2	3898.2	12.7

** Base Case*

The following alternative control strategies and schedules were simulated for this analysis.

24-hr Schedule

- Impact of three supply air temperature (SAT) reset methods.
- Impact of design SAT setpoint, simulated with constant SAT
- Impact of design SAT setpoint, with reset (temperature priority).
- Impact of design SAT setpoint, with reset (airflow priority)
- Impact of design SAT setpoint, with reset (simultaneous temperature and airflow)

5-day Schedule

- Impact of three supply air temperature (SAT) reset methods.
- Impact of design SAT setpoint, simulated with constant SAT
- Impact of design SAT setpoint, with reset (temperature priority).
- Impact of design SAT setpoint, with reset (airflow priority)

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[5] The building has a data center operating 24 hours, therefore the air handlers are operational 24 hours, throughout the week.

6.4 *Results*

The results are divided into two sections; one with 24-hr schedule, and the other with 5-day schedule.

Results 24-hr Schedule

Table 18: Energy Impact of Supply Air Temperature Reset Strategies – 24 Hour Operating Schedule

	Electricity (kWh)										Fuel (MBtu)	
	Cooling	% Diff	Heat Reject	% Diff	Pumps & Aux	% Diff	Fans	% Diff	Total	% Diff	Heating	% Diff
No Reset	518,955	201%	67,333	232%	243,541	111%	318,503	136%	2,320,183	121%	9,221	3094%
Reset by Warmest Zone	258,100	--	29,018	--	219,983	--	234,812	--	1,913,766	--	298.0	--
Reset by OAT	388,320	150%	54,053	186%	233,585	106%	210,717	90%	2,058,526	108%	3,144	1055%

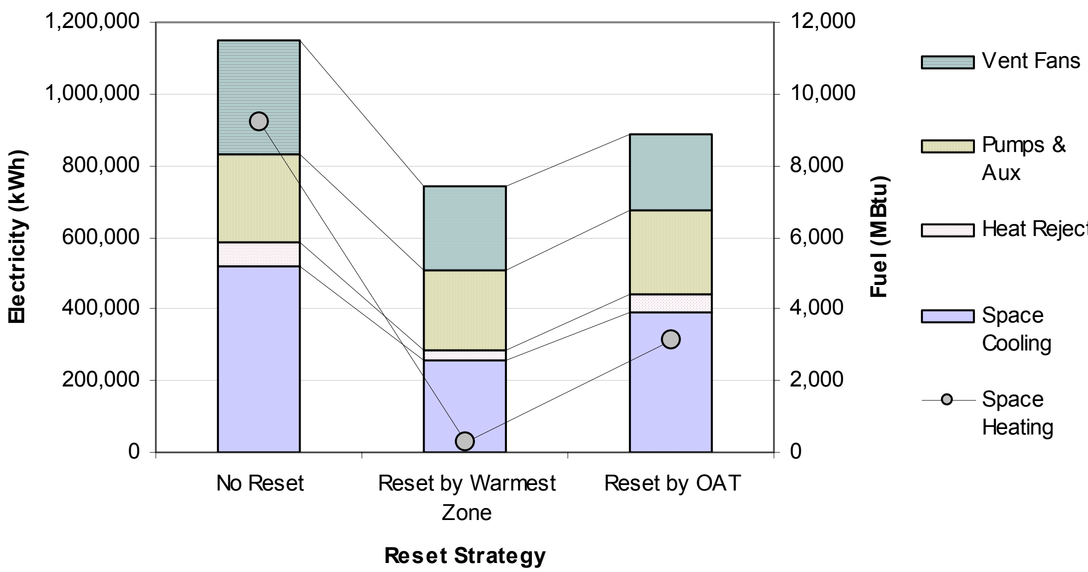


Figure 19: Impact of Supply Air Temperature Reset Strategies – 24 Hour Operating Schedule

Table 19: Utility Cost Impact of Supply Air Temperature Reset Strategies – 24 Hour Operating Schedule

	Electricity Energy	Electricity Demand	Electricity Total	Natural Gas Total	Total Utility	% Diff.
No Reset	$138,931	$75,816	$216,847	$46,697	$263,544	141%
Reset by Warmest Zone	$117,102	$65,467	$184,669	$1,982	$186,651	--
Reset by OAT	$124,912	$66,811	$193,824	$18,098	$211,922	114%

Table 20: Energy Impact of Varying SAT Design Setpoint - No SAT Reset (fixed SAT)

	Electricity (kWh)										Fuel (MBtu)	
	Cooling	% Diff	Heat Reject	% Diff	Pumps & Aux	% Diff	Fans	% Diff	Total	% Diff	Heating	% Diff
SAT 45 CHWT 36	694,051	124%	72,667	101%	250,670	102%	167,493	49%	2,356,733	98%	7,865.50	78%
SAT 47 CHWT 38	721,163	128%	85,222	118%	252,106	103%	261,457	76%	2,491,802	104%	10,343.80	102%
SAT 49 CHWT 40	691,297	123%	87,882	122%	250,649	102%	357,197	104%	2,558,876	107%	11,542.50	114%
SAT 51 CHWT 42	561,328	--	72,198	--	245,609	--	343,074	--	2,394,062	--	10,117.80	--
SAT 53 CHWT 44	463,495	83%	59,932	83%	242,891	99%	307,550	90%	2,245,720	94%	8,418.60	83%
SAT 55 CHWT 46	396,108	71%	50,665	70%	240,739	98%	290,668	85%	2,150,032	90%	6,970.40	69%
SAT 58 CHWT 49	311,855	56%	35,407	49%	236,764	96%	249,643	73%	2,005,521	84%	4,250.50	42%

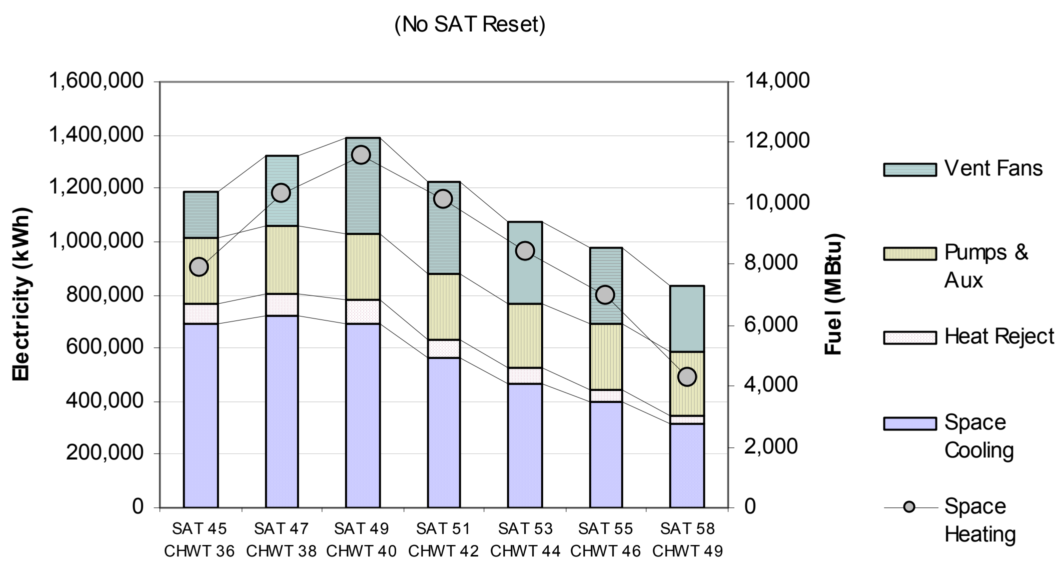


Figure 20: Energy Impact of Varying SAT Design Setpoint - No SAT Reset (fixed SAT)

Table 21: Utility Cost Impact of Varying SAT Design Setpoint - No SAT Reset (fixed SAT)

Fan Static (in. WG)	Electricity Energy	Electricity Demand	Electricity Total	Natural Gas Total	Total Utility	% Diff.
SAT 45 CHWT 36	$141,171	$71,242	$214,512	$40,958	$255,470	94%
SAT 47 CHWT 38	$148,667	$78,688	$229,454	$51,275	$280,729	103%
SAT 49 CHWT 40	$152,701	$81,112	$235,912	$56,297	$292,209	107%
SAT 51 CHWT 42	$143,024	$76,730	$221,855	$50,474	$272,329	--
SAT 53 CHWT 44	$134,586	$70,116	$206,802	$43,359	$250,161	92%
SAT 55 CHWT 46	$129,217	$66,451	$197,769	$37,326	$235,095	86%
SAT 58 CHWT 49	$121,346	$62,684	$186,129	$24,733	$210,862	77%

Table 22: Energy Impact of Varying SAT Design Setpoint – With SAT Reset by Warmest Zone (Reset Temperature First)

	Electricity (kWh)										Fuel (MBtu)	
	Cooling	% Diff	Heat Reject	% Diff	Pumps & Aux	% Diff	Fans	% Diff	Total	% Diff	Heating	% Diff
SAT 45 CHWT 36	314,114	121%	31,401	107%	221,015	101%	188,423	81%	1,926,805	101%	126.9	42%
SAT 47 CHWT 38	290,154	112%	30,789	104%	220,543	100%	228,128	98%	1,941,467	101%	182.2	60%
SAT 49 CHWT 40	272,888	105%	30,141	102%	220,326	100%	234,019	100%	1,929,227	101%	253.3	83%
SAT 51 CHWT 42	258,894	--	29,478	--	219,823	--	233,218	--	1,913,266	--	304.6	--
SAT 53 CHWT 44	247,456	96%	28,731	97%	219,767	100%	233,891	100%	1,901,698	99%	339.7	112%
SAT 55 CHWT 46	239,350	92%	28,095	95%	220,016	100%	240,656	103%	1,899,969	99%	366.7	120%
SAT 58 CHWT 49	233,287	90%	27,234	92%	220,811	100%	254,076	109%	1,907,261	100%	387.2	127%

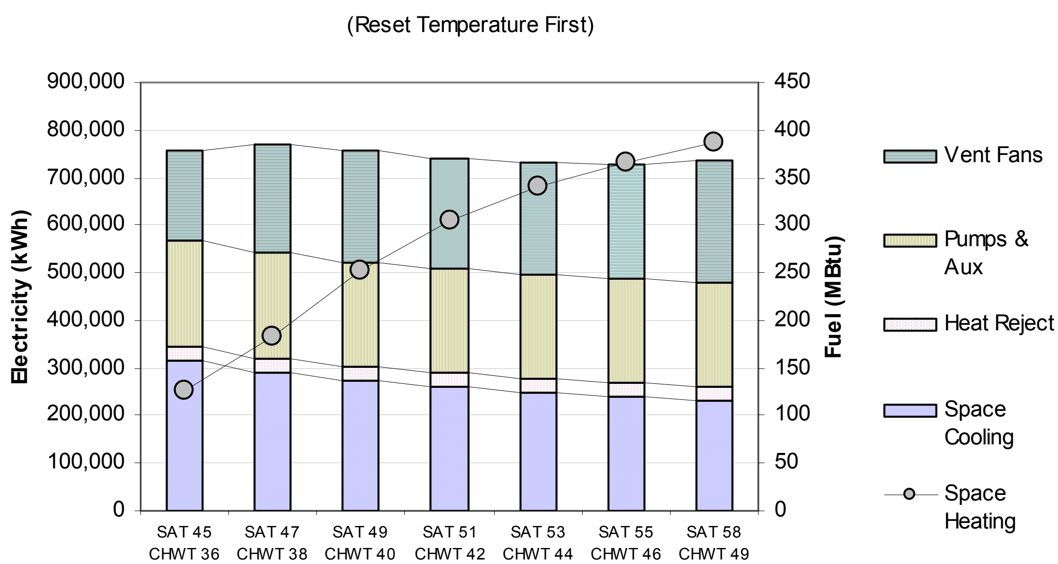


Figure 21: Energy Impact of Varying SAT Design Setpoint – With SAT Reset By Warmest Zone (Reset Temperature First)

Table 23: Utility Cost Impact of Varying SAT Design Setpoint – With SAT Reset by Warmest Zone (Reset Temperature First)

Fan Static (in. WG)	Electricity Energy	Electricity Demand	Electricity Total	Natural Gas Total	Total Utility	% Diff.
SAT 45 CHWT 36	$117,133	$64,446	$183,679	$2,848	$186,527	101%
SAT 47 CHWT 38	$116,498	$64,038	$182,637	$2,749	$185,386	100%
SAT 49 CHWT 40	$116,173	$63,769	$182,042	$3,315	$185,357	100%
SAT 51 CHWT 42	$115,714	$63,324	$181,138	$3,913	$185,051	--
SAT 53 CHWT 44	$115,216	$62,812	$180,129	$3,944	$184,073	99%
SAT 55 CHWT 46	$115,190	$62,617	$179,907	$3,533	$183,440	99%
SAT 58 CHWT 49	$115,974	$62,941	$181,015	$2,931	$183,946	99%

Table 24: Energy Impact of Varying SAT Design Setpoint - Reset by Warmest Zone (Reset Airflow First)

	Electricity (kWh)										Fuel (MBtu)	
	Cooling	% Diff	Heat Reject	% Diff	Pumps & Aux	% Diff	Fans	% Diff	Total	% Diff	Heating	% Diff
SAT 45 CHWT 36	336,051	124%	33,067	107%	225,524	101%	151,443	77%	1,917,938	101%	444.5	71%
SAT 47 CHWT 38	305,237	113%	31,943	104%	224,258	101%	174,110	88%	1,907,400	101%	427.2	69%
SAT 49 CHWT 40	285,821	105%	31,412	102%	223,616	100%	189,449	96%	1,902,151	100%	522.8	84%
SAT 51 CHWT 42	271,171	--	30,847	--	222,984	--	197,882	--	1,894,736	--	621.8	--
SAT 53 CHWT 44	257,232	95%	29,831	97%	222,500	100%	205,729	104%	1,887,144	100%	625.4	101%
SAT 55 CHWT 46	245,701	91%	28,746	93%	222,023	100%	218,966	111%	1,887,288	100%	556.2	89%
SAT 58 CHWT 49	235,776	87%	27,398	89%	221,714	99%	243,837	123%	1,900,577	100%	455.9	73%

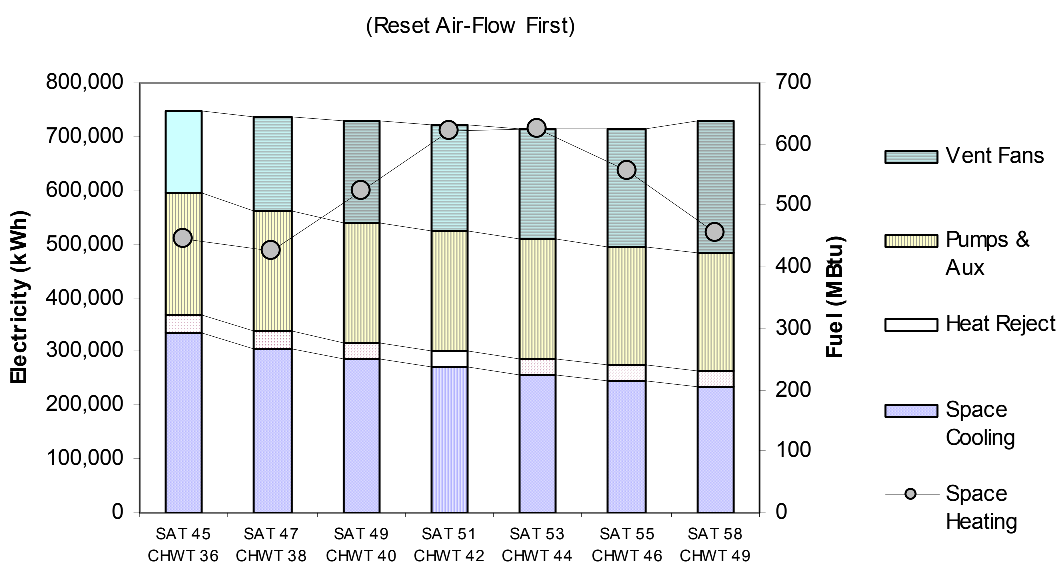


Figure 22: Energy Impact of Varying SAT Design Setpoint (Reset Airflow First)

Table 25: Utility Cost Impact of Varying SAT Design Setpoint – With SAT Reset by Warmest Zone (Reset Airflow First)

Fan Static (in. WG)	Electricity Energy	Electricity Demand	Electricity Total	Natural Gas Total	Total Utility	% Diff.
SAT 45 CHWT 36	$117,871	$66,052	$186,023	$954	$186,977	100%
SAT 47 CHWT 38	$118,999	$67,352	$188,451	$1,284	$189,735	102%
SAT 49 CHWT 40	$118,174	$66,377	$186,652	$1,711	$188,363	101%
SAT 51 CHWT 42	$117,091	$65,431	$184,622	$2,022	$186,644	--
SAT 53 CHWT 44	$116,314	$64,563	$182,977	$2,230	$185,207	99%
SAT 55 CHWT 46	$116,147	$64,226	$182,474	$2,390	$184,864	99%
SAT 58 CHWT 49	$116,476	$63,883	$182,459	$2,512	$184,971	99%

Table 26: Energy Impact of Varying SAT Design Setpoint - Reset by Warmest Zone (Reset Temperature & Airflow Simultaneously)

	Electricity (kWh)										Fuel (MBtu)	
	Cooling	% Diff	Heat Reject	% Diff	Pumps & Aux	% Diff	Fans	% Diff	Total	% Diff	Heating	% Diff
SAT 45 CHWT 36	319,651	122%	31,528	107%	222,340	101%	170,239	76%	1,915,609	100%	230.2	58%
SAT 47 CHWT 38	294,028	113%	30,848	104%	221,605	100%	203,897	91%	1,922,230	101%	263.8	66%
SAT 49 CHWT 40	275,680	106%	30,223	102%	221,322	100%	219,166	98%	1,918,244	101%	345.0	87%
SAT 51 CHWT 42	260,996	--	29,556	--	220,667	--	224,644	--	1,907,715	--	397.7	--
SAT 53 CHWT 44	248,989	95%	28,797	97%	220,446	100%	229,211	102%	1,899,295	100%	421.2	106%
SAT 55 CHWT 46	240,324	92%	28,120	95%	220,441	100%	237,821	106%	1,898,560	100%	422.7	106%
SAT 58 CHWT 49	233,586	89%	27,237	92%	221,002	100%	253,069	113%	1,906,747	100%	412.1	104%

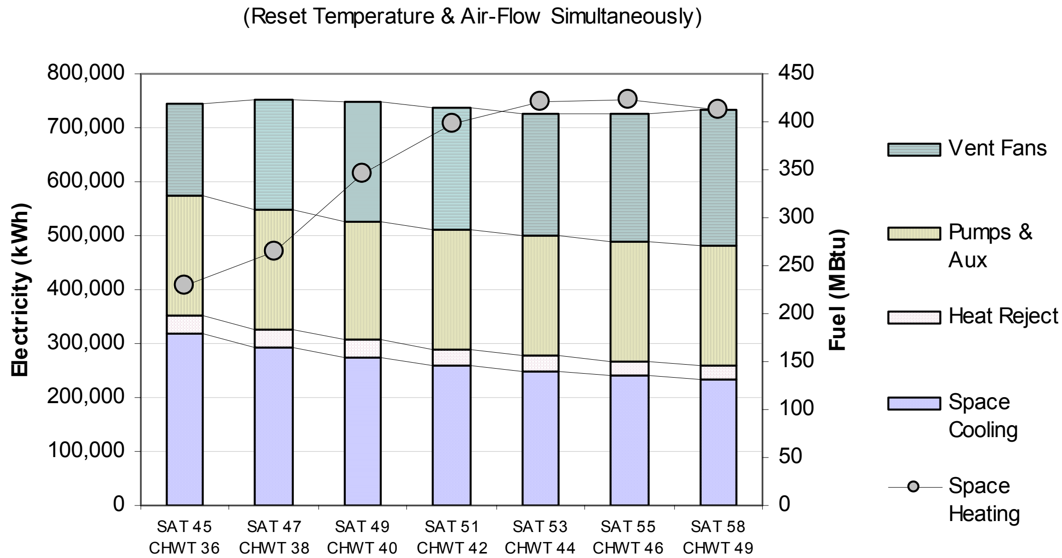


Figure 23: Energy Impact of Varying SAT Design Setpoint (Reset Temperature & Airflow Simultaneously)

Table 27: Utility Cost Impact of Varying SAT Design Setpoint – With SAT Reset by Warmest Zone (Reset Temperature & Airflow Simultaneously)

Fan Static (in. WG)	Electricity Energy	Electricity Demand	Electricity Total	Natural Gas Total	Total Utility	% Diff.
SAT 45 CHWT 36	$117,096	$65,260	$184,456	$1,584	$186,040	100%
SAT 47 CHWT 38	$117,673	$66,332	$186,106	$1,783	$187,889	101%
SAT 49 CHWT 40	$117,398	$65,833	$185,331	$2,268	$187,599	101%
SAT 51 CHWT 42	$116,689	$64,869	$183,658	$2,594	$186,252	--
SAT 53 CHWT 44	$116,134	$64,360	$182,593	$2,736	$185,329	100%
SAT 55 CHWT 46	$116,044	$64,067	$182,211	$2,741	$184,952	99%
SAT 58 CHWT 49	$116,442	$63,852	$182,395	$2,668	$185,063	99%

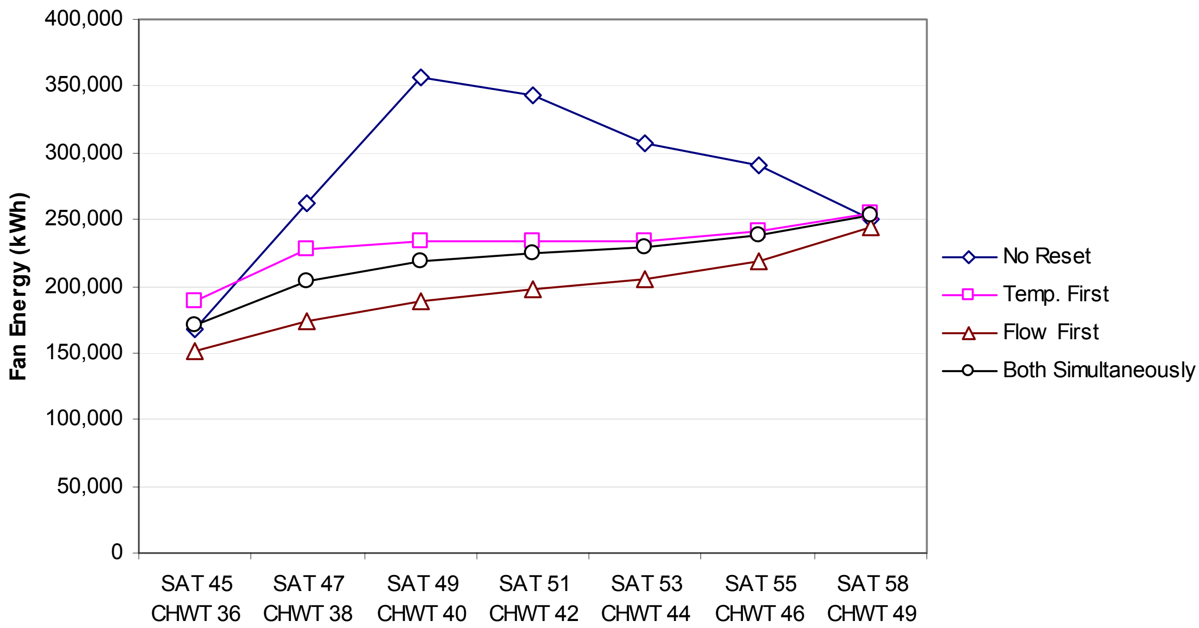


Figure 24: Fan Energy Variation Based on SAT Reset Strategy and as a Function of SAT Design Setpoint, 24-hour Operating Schedule

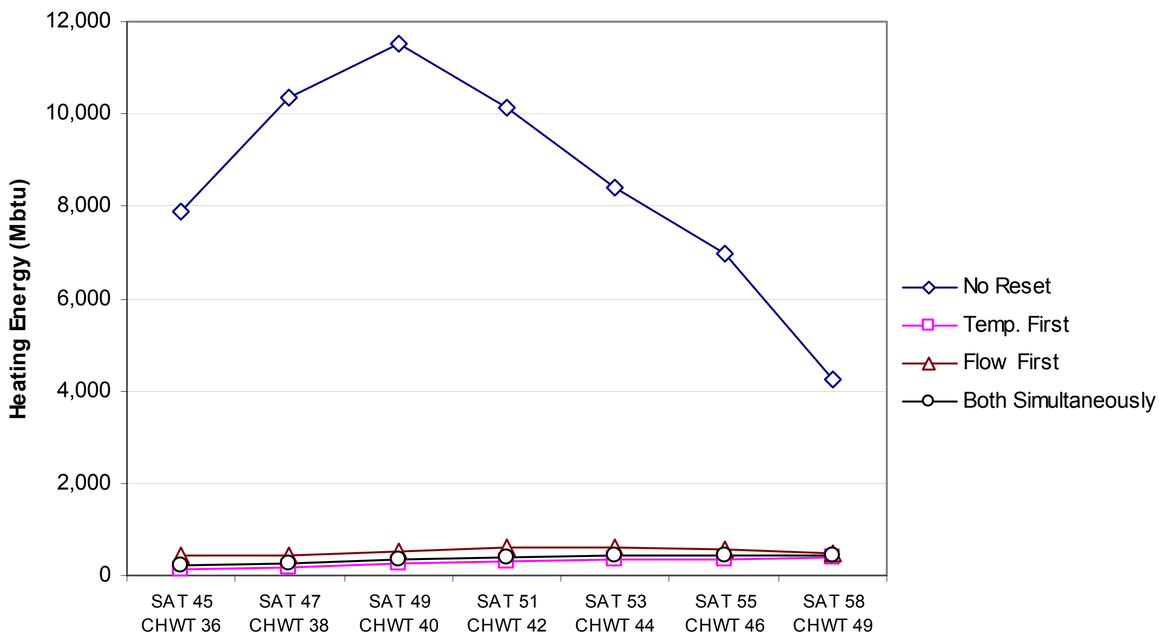


Figure 25: Heating Energy Use Variation Based on SAT Reset Strategy and as a Function of SAT Design Setpoint, 24-hour Operating Schedule

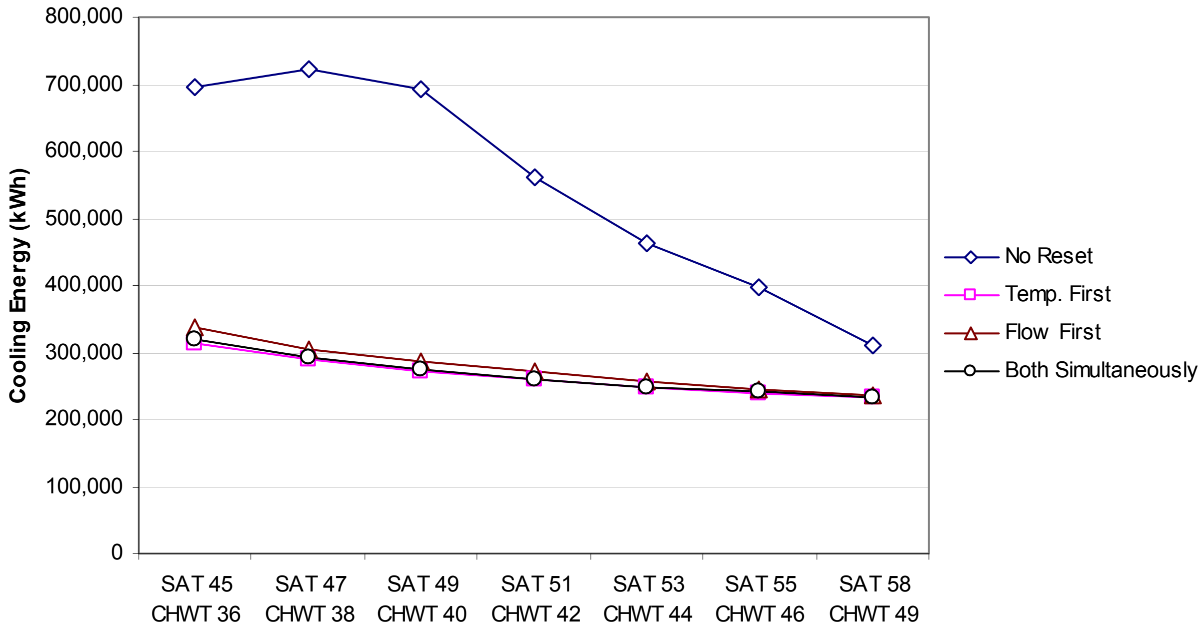


Figure 26: Cooling Energy Use Variation Based on SAT Reset Strategy and as a Function of SAT Design Setpoint, 24-hour Operating Schedule

Results with 5-day Schedule

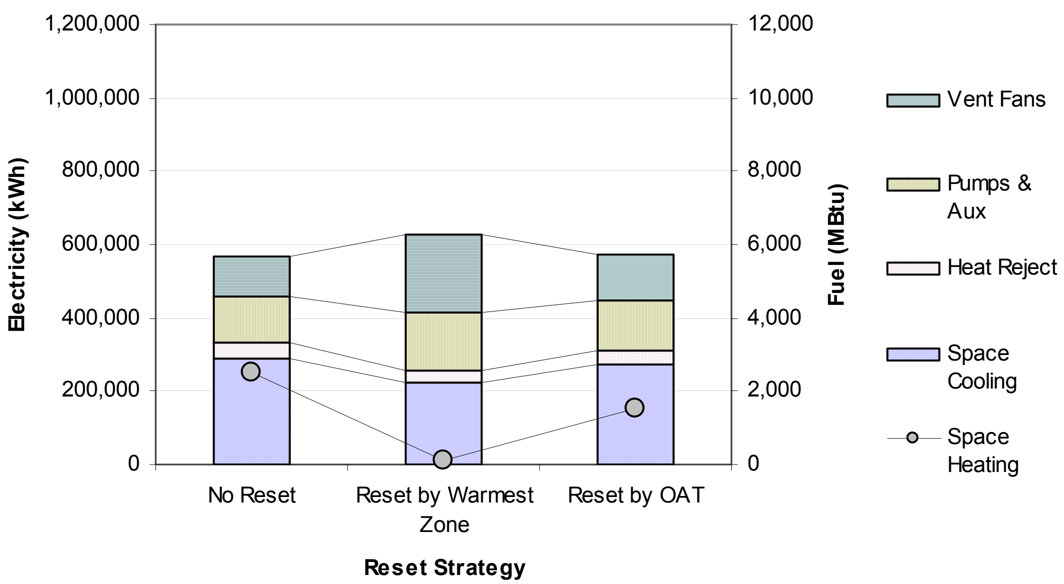


Figure 27: Energy Impact of SAT Reset Strategies - 5-day Schedule

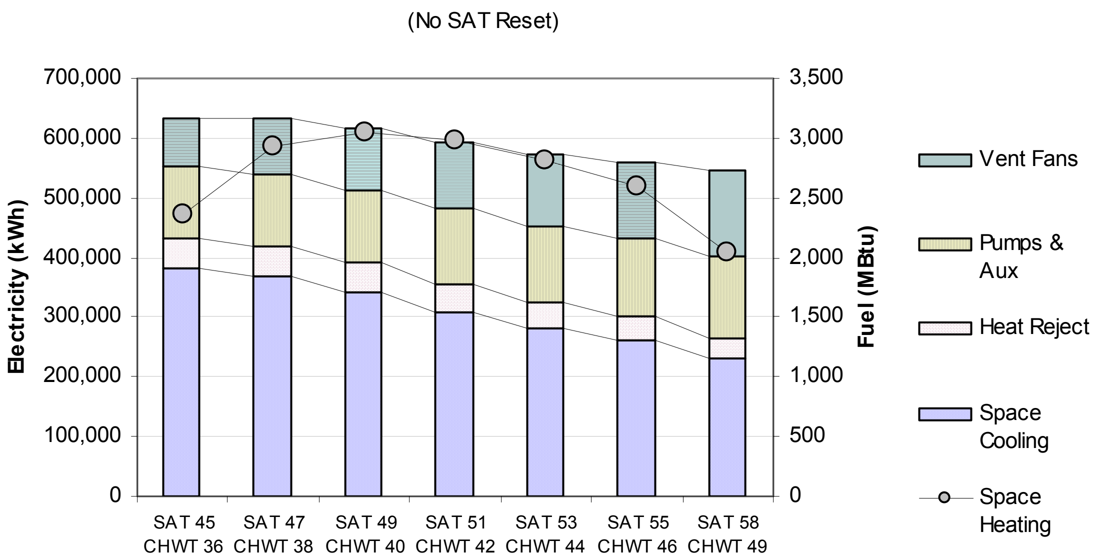


Figure 28: Energy Impact of Varying SAT Design Setpoint (No SAT Reset, 5-day Schedule)

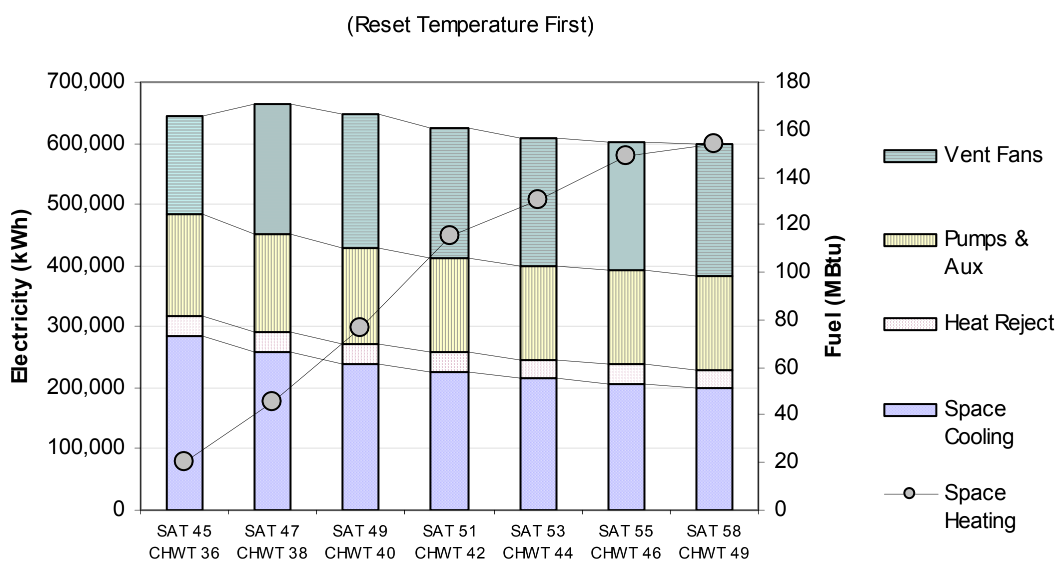


Figure 29: Energy Impact of Varying SAT Design Setpoint (Reset Temperature First, 5-day Schedule)

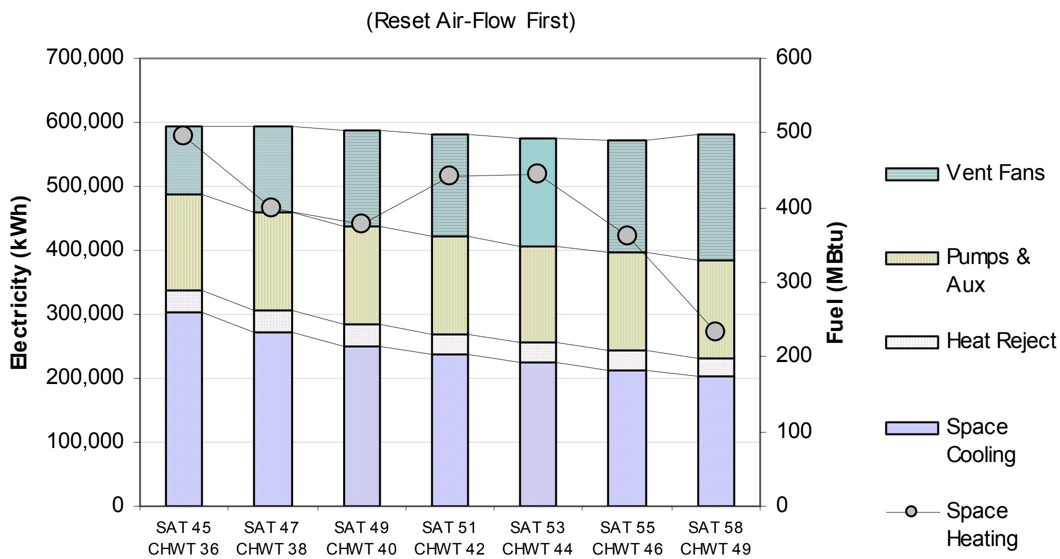


Figure 30: Energy Impact of Varying SAT Design Setpoint (Reset Airflow First, 5-day Schedule)

6.5 *Observations*

The primary observation is that supply air temperature control can have a very big impact on energy consumption. And the impact is largest for buildings with significant amount of low-load operating time such as a 24 hour facility. However, the case with fixed supply air temperature (no reset) may not be too realistic, because even in facilities without automatic control, the operating staff may adjust the SAT setpoint upwards during the winter when less cooling is required.

Some of the simulation results do not appear to be correct, but we have not yet been able to diagnose the problem. The errors appear in Figure 20 where the energy impact of SAT design setpoint is compared for the “no reset” case. We should see that cooling energy increases for the cases with lower SAT while fan energy decreases. This error does not seem to appear in cases with supply air temperature reset control.

In general, As the SAT setpoint increases, the fan energy increases and the cooling energy decreases (because the chilled water temperature is also raised and the chiller operates more efficiently). In theory there should be an optimal point that minimizes the sum of fan and cooling energy. In this analysis it turns out that the optimal (lowest energy cost) SAT setpoint is 55°F for almost all cases.

6.6 *Conclusions*

Due to the large impact of supply air temperature control, this topic deserves significant attention in the guidelines.

The implications for monitoring are that we want to have a good understanding of both air distribution system performance and chilled water plant performance. Fortunately, both of these are being measured at the first two monitoring sites. We also want to understand reheat energy system performance, and reheat energy is also being measured at the first two sites.

The data missing from the first two sites that would be useful in studying reset strategies is detailed zone-level temperature and airflow data. The large volume of data collection required and the potential load on the EMCS systems have so far prevented us from collecting that information at the first two sites. However, for site #3, which has a floor-by-floor system, we will be able to get the zone data. We should also try to get the data at sites #4 and #5 if possible.

7. VAV Box Sizing and Control

7.1 *Guideline Problem Description*

Terminal units that are larger than is required to meet zone loads tend to operate close to minimum air flow (operate like constant volume reheat systems). Fan energy savings opportunities are lost because air flow does not drop as loads drop. Cooling and reheat energy may also be higher than necessary.

Oversizing can occur for several reasons, including:

- Internal heat gain is conservatively overestimated.
- Actual number of occupants is overestimated.

7.2 *Sensitivity Analysis Goal*

The intent of the sensitivity analysis is to estimate the energy impact of varying minimum air flow setpoints for the VAV boxes.

7.3 *Methodology*

This measure was evaluated by simply running simulations varying the minimum airflow setpoint for VAV boxes from 20 percent to 60 percent. The base case assumption for all other simulations in this report is a 30 percent minimum.

7.4 *Results*

Table 28: Annual Energy Use by End use (VAV Box Sizing and Control, 24-hr Schedule)

	Electricity (kWh)										Fuel (MBtu)	
	Cooling	% Diff	Heat Reject	% Diff	Pumps & Aux	% Diff	Fans	% Diff	Total	% Diff	Heating	% Diff
60%	264,064	102%	30,654	105%	221,551	101%	382,898	162%	2,071,016	108%	487.6	162%
50%	260,652	101%	29,690	102%	220,901	100%	312,092	132%	1,995,188	104%	412.8	137%
40%	258,961	100%	29,276	101%	220,330	100%	264,733	112%	1,945,151	102%	341.8	113%
30%	258,167	100%	29,095	100%	220,016	100%	236,593	100%	1,915,723	100%	301.6	100%
20%	258,100	--	29,018	--	219,983	--	234,812	--	1,913,766	--	298.0	--

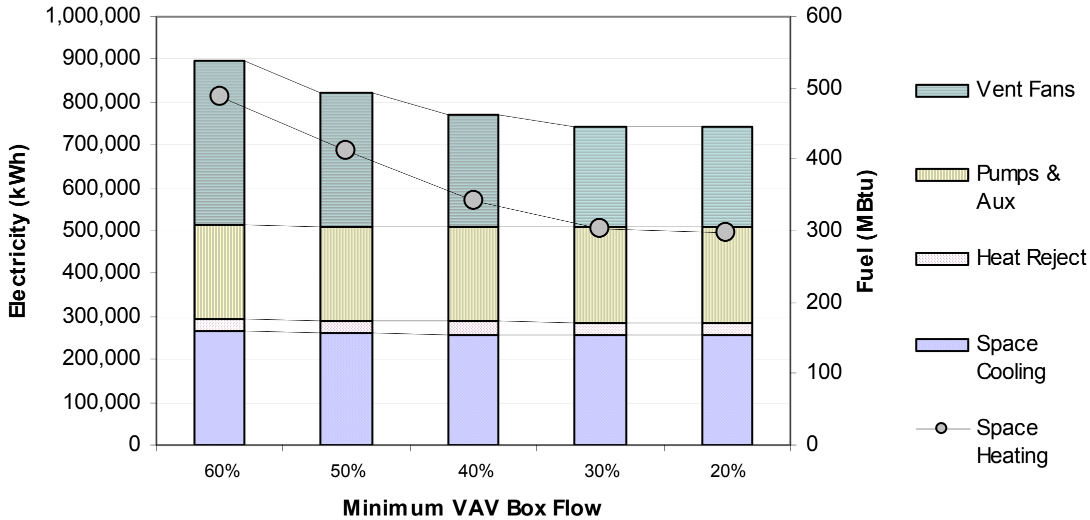


Figure 31: Annual HVAC Energy Use Comparison (VAV Box Sizing and Control, 24-hr Schedule)

Table 29: Utility Cost Comparison (VAV Box Sizing and Control, 24-hr Schedule)

Min VAV Flow	Electricity Energy	Electricity Demand	Electricity Total	Natural Gas Total	Total Utility	% Diff.
60%	$125,323	$65,604	$193,028	$3,109	$196,137	105%
50%	$121,240	$65,302	$188,643	$2,668	$191,311	102%
40%	$118,657	$65,306	$186,063	$2,242	$188,305	101%
30%	$117,202	$65,462	$184,764	$2,003	$186,767	100%
20%	$117,102	$65,467	$184,669	$1,982	$186,651	--

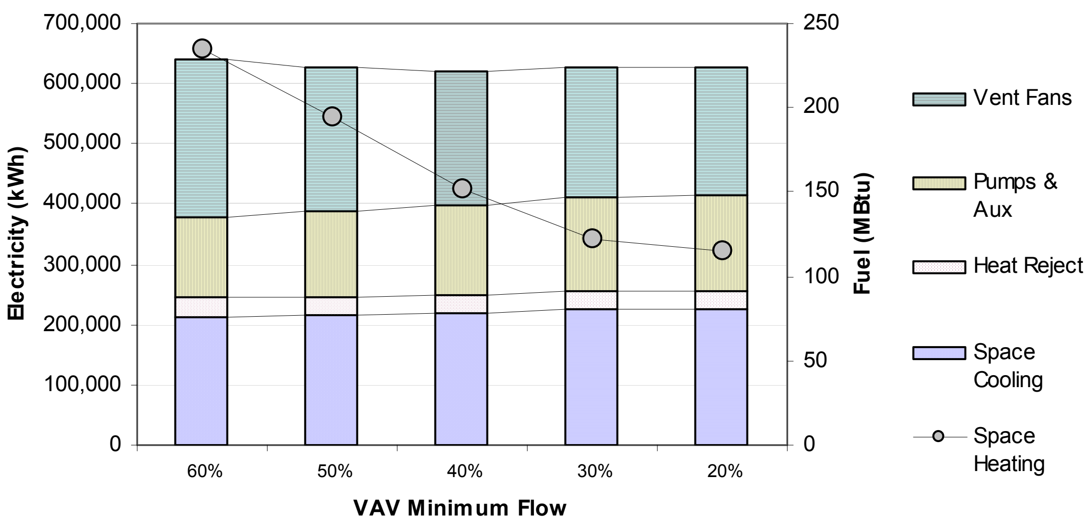


Figure 32: Annual HVAC Energy Use Comparison (VAV Box Sizing and Control, 5-day Schedule)

7.5 *Observations*

The fan energy impact of VAV box sizing is very significant when the building is simulated on the 24 hour operating schedule. Increasing the minimum flow fraction from 0.3 to 0.6 increases fan energy by 62%.

Reheat energy also increases by 62% when flow fraction is increased to 0.6 (approximately equivalent to oversized VAV boxes).

When the building is simulated with a normal 5-day office schedule, the impact on electricity use is quite a bit smaller. There is less impact on fan energy because there are fewer hours when boxes are at minimum flow. However, the reheat energy nearly doubles as fraction increases from 0.2 to 0.6.

7.6 *Conclusions*

There is potentially a modest impact to VAV box oversizing for buildings operating only during normal office hours and a very significant impact for 24-hour operation. The actual magnitude of the problem is not known at this point because zone-level air flow would have to be recorded to check on real VAV box behavior.

The zone level data are not necessarily required in order to develop guidelines for VAV box sizing, but the data would be useful to determine the magnitude of the problem in these specific buildings.

8. Fan-Powered Boxes

8.1 *Guideline Problem Description*

Inappropriate use of series fan-powered boxes increases cooling energy (due to introduction of warm induced air when it is not always necessary) and fan energy (due to lower efficiency of small fans).

8.2 *Sensitivity Analysis Goal*

The simple analysis goal is to estimate the energy impact of three system alternatives: standard VAV boxes, parallel-fan powered boxes and series fan powered boxes.

8.3 *Methodology*

This measure was simulated by creating three alternatives in DOE2.2. The fan powered boxes are represented by the system type “Powered Induction Units”. The “induced” air comes from the interior zones and the fan-powered boxes serve the perimeter zones.

For the parallel fan case, the fan is sized at 50% of peak primary zone air flow, and the fan efficiency is assumed to be 0.5 W/cfm. The fan is controlled to turn on when the zone temperature drops to within 1°F of the heating setpoint. If the induced air is warm enough to keep the space temperature from dropping then reheat is avoided. Otherwise, a reheat coil provides supplemental heat.

In the series-fan case, the zone fan runs continuously, drawing a varying fraction of air from the induced zone depending on the position of the primary air damper. In the model, the fan power is assumed to be 0.4 W/cfm. Since this fan is in series with the main supply fan it reduces the supply fan's pressure requirement. For this analysis, the supply fan static pressure was reduced from 4.0 to 3.67 in. w.c. in the series fan case.

8.4 *Results*

The fan powered boxes result in significantly lower heating energy use because much of the reheat energy is offset by the induced air from the interior zone. The series fan boxes provide the lowest reheat energy.

The fan energy use increases by 94% for the series fan powered box case because the zone fans operate continuously and are much less efficient than the main supply fan. The simulation results show that total fan energy drops slightly for the parallel fan system. This result is counter-intuitive because it seems that any parallel fan operation would add to the base case fan power. More detailed analysis will be necessary to validate this result.

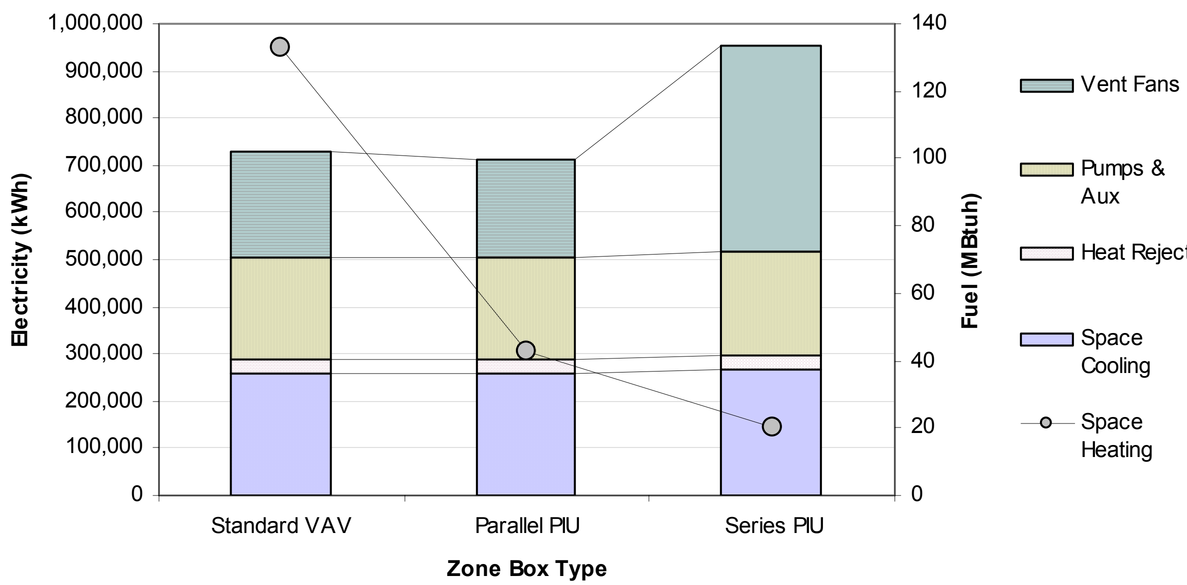


Figure 33: Annual HVAC Energy Use Comparison

Table 30: Annual HVAC Energy Use by End use

	Electricity (kWh)										Fuel (MBtu)	
	Cooling	% Diff	Heat Reject	% Diff	Pumps & Aux	% Diff	Fans	% Diff	Total	% Diff	Heating	% Diff
Standard VAV	258,092	--	29,142	--	218,064	--	224,340	--	1,901,491	--	133.1	--
Parallel PIU	257,976	100%	29,155	100%	217,686	100%	207,714	93%	1,884,383	99%	42.6	32%
Series PIU	266,420	103%	31,665	109%	217,633	100%	436,140	194%	2,123,711	112%	20.0	15%

Table 31: Utility Cost Comparison

Min VAV Flow	Electricity Energy	Electricity Demand	Electricity Total	Natural Gas Total	Total Utility	% Diff.
Standard VAV	$116,463	$65,189	$183,752	$993	$184,745	--
Parallel PIU	$115,645	$65,534	$183,278	$431	$183,709	99%
Series PIU	$129,586	$70,986	$202,671	$288	$202,959	110%

8.5 *Observations*

Series fan powered boxes appear to significantly increase energy costs. The reduction in reheat energy cost is dwarfed by the increase in fan energy.

Parallel fan-powered boxes do not have a large impact on energy cost in this model. This may be true of California climates in general because reheat energy is relatively low in the first place.

8.6 *Conclusions*

Due to the magnitude of the potential impact, series fan-powered boxes are worth addressing in the guidelines. However, series boxes are not present in any of the surveyed sites, so the impact may not be to big in California.

The use of parallel fan-powered boxes seems like it can be a lower priority for guideline development. Monitoring Site #3 has parallel boxes and may provide more insight into their benefits as monitoring proceeds.

9. System Effects Case Studies (Air Side)

9.1 *Guideline Problem Description*

Unexpected air pressure loss, and subsequent fan energy waste, can result from specific arrangements of fan, ducts and/or fittings.

9.2 *Conclusions*

Impacts will be similar to duct sizing results presented earlier. Mitigation of system effects will reduce fan pressure just as increasing duct size will reduce pressure losses.

10. Supply Pressure Reset Schemes

10.1 *Guideline Problem Description*

VAV supply duct air pressure is typically controlled to a specific setpoint that ensures that the zone farthest from the fan receives adequate airflow. The pressure may be set higher than necessary just to make sure it is high enough. Quite often, it is likely that lower pressure would satisfy zone air flow requirements. Therefore, fan pressure is higher than necessary for much of the time and fan energy is wasted.

10.2 *Methodology*

Supply pressure reset has not been evaluated in the sensitivity analysis because it cannot be modeled directly in DOE2.2.

10.3 *Conclusions*

This measure will require zone level monitored data for accurate evaluation.

The potential impact is probably similar to the cooling coil bypass dampers. If so, then the impact on fan energy will be modest.

11. Demand Controlled Ventilation

11.1 *Guideline Problem Description*

Introduction of outside ventilation air creates a heating and cooling load when it’s cold or hot outside, and the volume of ventilation air can have a big impact on HVAC energy consumption. With demand controlled ventilation the amount of ventilation air is varied depending on occupancy so the that rate is no larger than necessary to maintain air quality.

11.2 *Conclusions*

Demand controlled ventilation has not been evaluated in the sensitivity analysis, because it appeared at the time of the simulation work that there would not be a good site available with high occupancy spaces to performance CO2 monitoring. However, it the CO2 monitoring may still happen and DCV will be evaluated in future analysis.

12. Night Time Purge

In the guidelines we will reference the PIER research done at LBNL on building mass precooling. No specific monitoring or analysis will be performed because the work is being done elsewhere. The magnitude of the impact is not yet known.

13. Reheat Control and Source

13.1 Guideline Problem Description

Hot water reheat systems with gas boilers offer lower energy costs (theoretically) than electric reheat systems, but hot water systems are typically more expensive. However, the actual relative energy costs are not well known.

13.2 Sensitivity Analysis Goal

Determine the magnitude of the energy cost difference between hot water and electric reheat systems.

13.3 Methodology

To analyze this measure, the reheat source in the simulation model was changed from hot water (with gas boiler) to electric resistance.

13.4 Results

The reheat source has a very small (~1%) impact on the total utility cost of the building in this climate.

Table 32: HVAC Energy Use by End use

	Electricity (kWh)							Fuel (MBtu)
	Cooling	Heating	Heat Reject	Pumps & Aux	Fans	Total	% Diff	Heating
Fuel Reheat	258,100	0	29,018	219,983	234,812	1,913,766	100%	298
Electricity Reheat	258,107	31,242	29,019	217,468	234,849	1,942,537	102%	0

Table 33: Total HVAC Energy Use Comparison

	HVAC Energy					
	Electric (kWh)	% Diff	Nat Gas (Therms)	% Diff	Total (Mbtu)	% Diff
Fuel Reheat	741,913	100%	2,980	100%	2,830	100%
Electricity Reheat	770,685	104%	0	0%	2,630	93%

Table 34: Utility Cost Comparison

Fan Static (in. WG)	Electricity Energy	Electricity Demand	Electricity Total	Natural Gas Total	Total Utility	% Diff.
Fuel Reheat	$117,102	$65,467	$184,669	$1,982	$186,651	100%
Electricity Reheat	$118,621	$67,981	$188,701	$161	$188,862	101%

13.5 Observations

The impact on energy cost is smaller than anticipated, but makes sense in this model due to the already low reheat energy requirement.

Electric reheat turns out to be slightly more expensive.

But don't know actual losses at this point.

These results assumes good supply air temperature reset control. If the system were operated with fixed supply air temperature then there would be much more reheat energy and a larger difference in cost between hot water and electric options. So we may be underestimating the relative energy cost for electric reheat.

On the other hand, the distribution heat loss in a hot water reheat system is not yet clear and we may be underestimating the energy consumption of that option.

13.6 *Conclusions*

These results seem to suggest that the source of reheat is not that important as a guideline topic, at least in mild California. But that conclusion is probably premature until the monitored reheat energy data is evaluated.

14. Load Calculation Issues

14.1 *Guideline Problem Description*

Overestimates of zone cooling loads can lead to system inefficiencies caused by VAV box oversizing (discussed earlier) and possibly reduced cooling plant efficiency when operating at partial load.

14.2 *Methodology*

Impacts of fan, coil and duct sizing are addressed by other measures.

Appendix A – Fan Properties

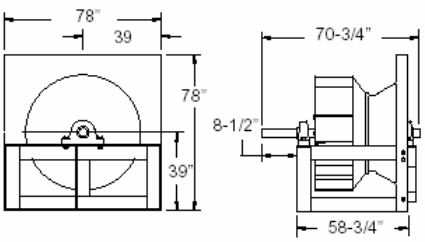
Data 660 CPL-A, 660 CPL-F

660 CPL-A
Wheel Diameter - 66"
Wheel Type - Airfoil
Tip Speed (FPM) = 17.28 x RPM
Max. BHP = 293 x $(RPM/1000)^3$
Inlet Area - 26.15 Sq. Ft.
Outlet Area - 28.51 Sq. Ft.
Outlet Velocity (FPM) = CFM/28.51

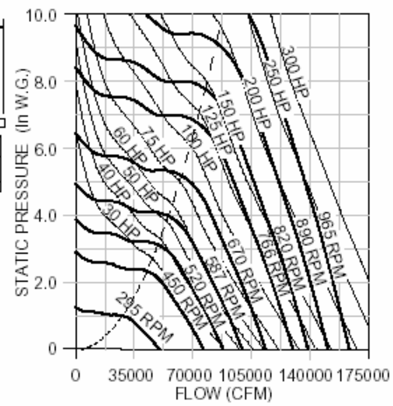
Class I Max. RPM - 587
Class II Max. RPM - 766
Class III Max. RPM - 965

660 CPL-F
Wheel Diameter - 66"
Wheel Type - Flat Blade
Tip Speed (FPM) = 17.28 x RPM
Max. BHP = 313 x $(RPM/1000)^3$
Inlet Area - 26.15 Sq. Ft.
Outlet Area - 28.51 Sq. Ft.
Outlet Velocity (FPM) = CFM/28.51

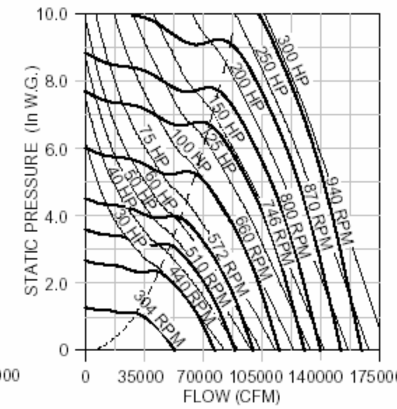
Class I Max. RPM - 572
Class II Max. RPM - 746
Class III Max. RPM - 940



660 CPL-A



660 CPL-F



660 CPL-A

CFM	OV	1.000 SP		1.500 SP		2.000 SP		2.500 SP		3.000 SP		4.000 SP		5.000 SP		6.000 SP		8.000 SP		10.000 SP	
		RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP
28500	999	295	6.80																		
35000	1227	313	8.82	362	12.6																
41500	1455	339	11.4	378	15.4	420	19.9														
48000	1683	369	14.5	403	19.2	437	23.8	473	28.8												
54500	1911	399	17.9	432	23.5	462	28.9	491	33.9	523	39.6										
61000	2139	430	21.9	462	28.3	490	34.5	517	40.5	543	46.1	599	58.7								
67500	2367	462	26.7	492	33.5	520	40.7	545	47.5	569	54.0	617	66.8	668	81.0						
74000	2595	495	32.2	524	39.7	550	47.2	574	54.9	597	62.4	640	76.4	685	90.8	732	107				
80500	2823	529	38.5	555	46.4	581	54.7	605	63.2	627	71.6	668	87.5	707	103	749	118				
87000	3051	564	45.7	588	54.4	612	63.0	635	71.9	657	81.2	697	99.1	734	116	771	132	849	168		
93500	3279	598	53.5	621	63.0	644	72.5	666	81.8	687	91.5	726	111	762	130	796	148	866	184	941	224
10000	3507	634	62.6	655	72.8	677	83.1	698	93.1	718	103	756	124	791	145	824	164	888	202	956	242
10650	3735	670	72.7	690	83.7	710	94.5	730	105	749	116	787	138	821	160	853	182	913	222		
11300	3963	706	83.9	725	95.6	744	107	762	118	781	130	817	152	851	176	882	200	941	245		
11950	4191	743	96.5	760	109	778	121	796	133	814	145	848	169	881	193	912	218				
12600	4419	779	110	796	123	813	136	830	149	846	161	880	187	912	212	942	238				
13250	4647	816	125	832	139	848	152	864	166	880	179	912	206	943	232						
13900	4875	853	142	869	156	884	171	899	185	914	199	945	227								
14550	5103	890	160	905	175	919	189	933	204	948	219										
15200	5331	927	179	941	194	955	210														

490 CPL-A, 490 CPL-F Data

490 CPL-A

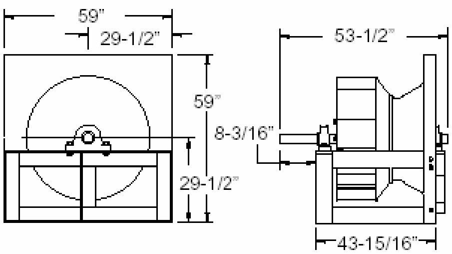
Wheel Diameter - 49"
Wheel Type - Airfoil
Tip Speed (FPM) = 12.83 x RPM
Max. BHP = 73.8 x $(RPM/1000)^3$
Inlet Area - 14.42 Sq. Ft.
Outlet Area - 15.71 Sq. Ft.
Outlet Velocity (FPM) = CFM/15.71

Class I Max. RPM - 793
Class II Max. RPM - 1035
Class III Max. RPM - 1303

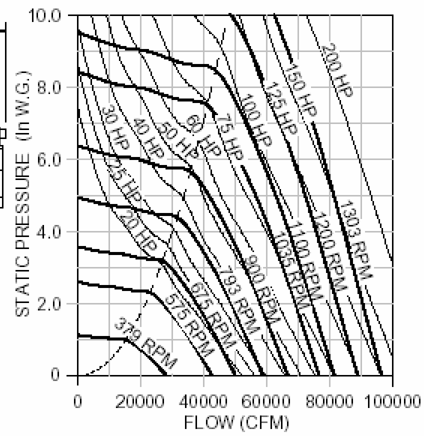
490 CPL-F

Wheel Diameter - 49"
Wheel Type - Flat Blade
Tip Speed (FPM) = 12.83 x RPM
Max. BHP = 76.4 x $(RPM/1000)^3$
Inlet Area - 14.42 Sq. Ft.
Outlet Area - 15.71 Sq. Ft.
Outlet Velocity (FPM) = CFM/15.71

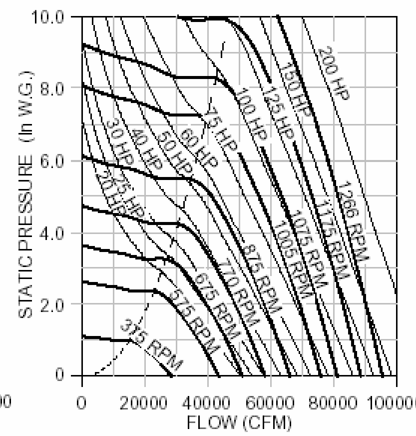
Class I Max. RPM - 770
Class II Max. RPM - 1005
Class III Max. RPM - 1266



490 CPL-A



490 CPL-F



490 CPL-A

CFM	OV	1.000 SP		1.500 SP		2.000 SP		2.500 SP		3.000 SP		4.000 SP		5.000 SP		6.000 SP		8.000 SP		10.000 SP	
		RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP
15300	973	379	3.70																		
19700	1253	412	5.15	470	7.21																
24100	1533	452	6.77	504	9.43	552	11.9	600	14.6												
28500	1813	496	8.72	544	11.8	588	15.0	629	18.0	669	21.0										
32900	2093	544	11.2	587	14.6	628	18.2	667	21.9	703	25.4	773	32.4								
37300	2373	594	14.3	633	17.9	671	21.9	707	26.0	742	30.2	806	38.2	867	45.9						
41700	2653	646	18.1	682	22.0	717	26.2	750	30.5	783	35.2	844	44.4	902	53.6	956	62.0				
46100	2933	700	22.6	733	26.9	764	31.1	796	35.9	826	40.7	885	51.1	939	61.2	991	71.2	1090	90.4		
50500	3213	754	27.9	784	32.4	814	37.1	843	42.0	871	47.0	927	58.0	979	69.2	1029	80.5	1122	102	1212	123
54900	3493	808	33.8	837	38.9	865	43.9	893	49.2	919	54.4	971	65.8	1021	77.9	1069	90.2	1159	114	1242	137
59300	3773	864	40.9	891	46.3	918	51.8	943	57.2	968	62.8	1017	74.6	1064	87.1	1110	100	1197	127	1278	153
63700	4053	919	48.6	946	54.8	971	60.6	995	66.4	1019	72.4	1064	84.4	1109	97.4	1153	111	1237	140		
68100	4333	976	57.7	1001	64.2	1025	70.5	1048	76.8	1070	83.0	1114	95.8	1156	109	1198	123	1278	153		
72500	4613	1032	67.6	1056	74.6	1079	81.5	1101	88.1	1123	94.9	1164	108	1204	122	1244	137				
76900	4893	1089	79.0	1111	86.1	1134	93.6	1155	101	1176	108	1215	122	1254	136	1291	151				
81300	5173	1147	91.8	1168	99.3	1189	107	1210	115	1229	122	1267	137								
85700	5453	1204	106	1225	114	1245	122	1264	130	1283	138										
90100	5733	1260	120	1280	129	1300	138														

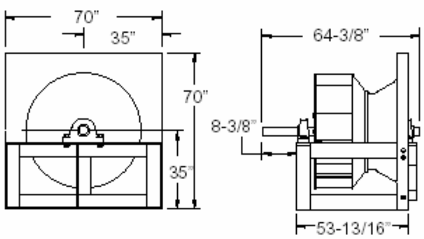
600 CPL-A, 600 CPL-F Data

600 CPL-A
Wheel Diameter - 60"
Wheel Type - Airfoil
Tip Speed (FPM) = 15.71 x RPM
Max. BHP = 182 x $(RPM/1000)^3$
Inlet Area - 21.55 Sq. Ft.
Outlet Area - 23.56 Sq. Ft.
Outlet Velocity (FPM) = CFM/23.56

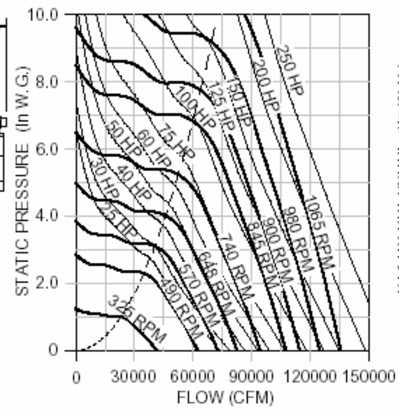
Class I Max. RPM - 648
Class II Max. RPM - 845
Class III Max. RPM - 1065

600 CPL-F
Wheel Diameter - 60"
Wheel Type - Flat Blade
Tip Speed (FPM) = 15.71 x RPM
Max. BHP = 195 x $(RPM/1000)^3$
Inlet Area - 21.55 Sq. Ft.
Outlet Area - 23.56 Sq. Ft.
Outlet Velocity (FPM) = CFM/23.56

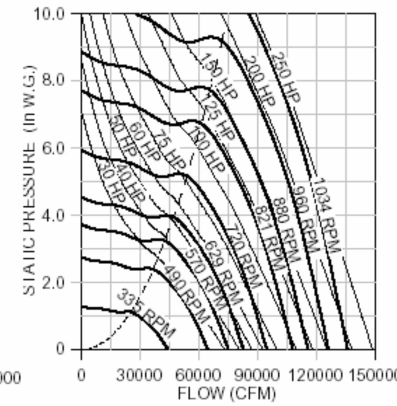
Class I Max. RPM - 629
Class II Max. RPM - 821
Class III Max. RPM - 1034



600 CPL-A



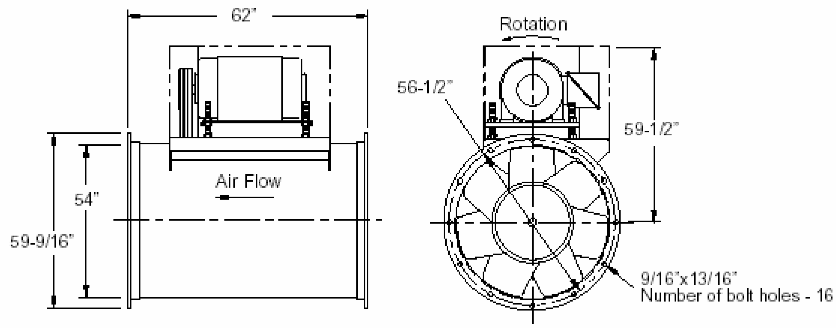
600 CPL-F



600 CPL-A

CFM	OV	1.000 SP		1.500 SP		2.000 SP		2.500 SP		3.000 SP		4.000 SP		5.000 SP		6.000 SP		8.000 SP		10.000 SP	
		RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP
23600	1001	325	5.65																		
29000	1230	344	7.28	398	10.4																
34400	1459	374	9.54	417	12.8	462	16.4														
39800	1689	406	12.0	444	15.9	481	19.7	521	24.0												
45200	1918	440	14.9	476	19.6	509	24.0	541	28.2	576	32.9										
50600	2147	475	18.3	509	23.5	540	28.6	569	33.5	598	38.3	659	48.6								
56000	2376	510	22.2	543	27.9	573	33.8	601	39.5	627	44.9	680	55.6	735	67.1						
61400	2605	546	26.8	577	32.9	607	39.4	633	45.7	658	51.9	706	63.7	755	75.6	806	88.5				
66800	2835	584	32.1	613	38.8	641	45.6	667	52.6	691	59.5	736	72.7	779	85.2	825	98.4	919	128		
72200	3064	622	38.0	649	45.4	675	52.5	700	59.8	724	67.4	768	82.3	809	96.4	849	110	935	139		
77600	3293	661	44.8	686	52.7	711	60.5	735	68.3	758	76.2	801	92.5	840	108	877	123	954	153	1035	186
83000	3522	700	52.3	723	60.7	747	69.2	770	77.5	792	85.8	834	103	872	120	908	137	979	168	1053	202
88400	3751	740	60.8	762	69.9	783	78.6	805	87.5	827	96.5	868	115	905	133	940	151	1007	185		
93800	3980	780	70.2	800	79.7	821	89.4	841	98.6	862	108	902	127	939	147	973	166	1037	203		
99200	4210	820	80.5	840	90.9	859	101	878	111	898	121	936	141	972	161	1006	182				
10460	4439	861	92.1	879	103	898	114	916	124	934	135	971	156	1006	177	1040	199				
11000	4668	902	105	919	116	936	127	954	139	971	149	1007	172	1041	194						
11540	4897	943	119	959	130	976	142	992	154	1009	166	1043	189								
12080	5126	983	133	999	146	1015	158	1031	171	1047	183										
12620	5356	1024	150	1040	163	1055	176														

Data VAB 54



Prop Diameter - 53.75"
Maximum Frame - 405T
Tip Speed (FPM) = 14.07 x RPM
Sound Data - Page 24
Approx. Shipping Wt.-Lbs. - 1941
(less motor)

54 VAB

CFM	OV	0" SP		1/2" SP		1" SP		1-1/2" SP		2" SP		2-1/2" SP		3" SP		3-1/2" SP	
		RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP
24500	1540	370	1.68	451	3.73	520	6.27										
27000	1698	408	2.25	483	4.45	546	7.13										
29500	1855	446	2.94	515	5.29	575	8.09	633	11.31								
32000	2012	484	3.75	549	6.29	605	9.19	657	12.50	711	16.21						
34500	2169	522	4.70	583	7.43	636	10.46	685	13.90	735	17.75						
37000	2326	559	5.79	618	8.70	668	11.88	714	15.41	760	19.29	806	23.52				
39500	2484	597	7.05	652	10.15	700	13.45	744	17.09	787	21.13	831	25.46	875	30.21		
42000	2641	635	8.48	687	11.75	733	15.20	775	19.00	816	23.05	856	27.46	898	32.32		
44500	2798	673	10.08	723	13.54	766	17.17	807	21.01	845	25.23	884	29.80	924	34.81	962	39.89
47000	2955	711	11.88	758	15.53	800	19.29	839	23.34	876	27.62	913	32.31	949	37.30	986	42.57
49500	3112	748	13.88	794	17.74	834	21.69	872	25.85	908	30.26	943	35.05	977	40.11	1012	45.45
52000	3270	786	16.09	830	20.10	869	24.25	905	28.57	940	33.21	974	38.10	1006	43.19	1039	48.53
54500	3427	824	18.52	866	22.77	903	27.05	938	31.51	972	36.22	1004	41.15	1036	46.41	1067	51.91
57000	3584	862	21.19	902	25.62	938	30.06	972	34.68	1004	39.49	1036	44.58	1066	50.02	1097	55.67
59500	3741	900	24.10	938	28.73	973	33.35	1006	38.13	1038	43.18	1069	48.45	1098	53.85	1126	59.40
62000	3898	937	27.27	975	32.06	1009	36.95	1041	41.88	1071	47.00	1101	52.42	1129	57.96	1157	63.61
64500	4056	975	30.70	1011	35.69	1044	40.76	1075	45.88	1105	51.14	1133	56.52	1162	62.37	1189	68.40
67000	4213	1013	34.41	1048	39.61	1080	44.85	1110	50.16	1139	55.64	1167	61.19	1193	66.85	1221	73.26
69500	4370	1051	38.41	1085	43.81	1115	49.15	1145	54.72	1173	60.29	1200	66.00	1227	72.05	1252	78.18
72000	4527	1089	42.70	1121	48.28	1151	53.88	1180	59.59	1207	65.36	1234	71.22	1260	77.38	1284	83.49
74500	4684	1126	47.30	1158	53.06	1187	58.85	1215	64.68	1242	70.62	1267	76.60	1292	82.84	1317	89.31
77000	4841	1164	52.23	1195	58.18	1223	64.19	1251	70.24	1277	76.36	1301	82.46	1327	89.12	1351	95.64
79500	4999	1202	57.48	1232	63.65	1259	69.80	1286	76.05	1311	82.33	1336	88.85	1360	95.23	1383	101.7
82000	5156	1240	63.08	1269	69.43	1296	75.82	1321	82.12	1346	88.68	1370	95.11	1394	101.9	1417	108.8
84500	5313	1278	69.02	1306	75.61	1332	82.15	1357	88.76	1381	95.27	1405	102.1	1429	109.2		
87000	5470	1315	75.33	1343	82.11	1368	88.78	1393	95.53	1417	102.5	1440	109.4				
89500	5627	1353	82.02	1380	88.96	1405	95.88	1429	102.9	1453	110.0						
92000	5785	1391	89.08	1417	96.25	1441	103.3										
94500	5942	1429*	96.54	1454	103.9												

CFM	OV	4" SP		4-1/2" SP		5" SP		5-1/2" SP		6" SP		6-1/2" SP		7" SP		7-1/2" SP	
		RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP	RPM	BHP
47000	2955	1022	47.93														
49500	3112	1045	50.74	1080	56.61												
52000	3270	1072	54.23	1104	60.00	1139	66.35										
54500	3427	1097	57.55	1130	63.70	1161	69.85	1191	75.93								
57000	3584	1128	61.71	1157	67.79	1186	73.72	1215	80.14	1247	87.08						
59500	3741	1155	65.52	1184	71.67	1212	78.02	1242	84.81	1270	91.39	1299	98.46	1330	106.0		
62000	3898	1185	69.84	1212	76.04	1240	82.79	1267	89.30	1295	96.23	1321	102.8				
64500	4056	1215	74.43	1242	81.00	1268	87.42	1295	94.34	1319	100.9	1348	108.7				
67000	4213	1246	79.33	1272	85.94	1298	92.72	1322	99.19	1349	107.0						
69500	4370	1278	84.61	1302	91.22	1327	97.96	1351	104.8								
72000	4527	1310	90.30	1334	96.90	1358	104.0										
74500	4684	1342	96.07	1366	103.0												
77000	4841	1373	101.9	1397	109.3												
79500	4999	1406	108.8														

Performance shown is for installation type D: ducted inlet, ducted outlet. Power rating (BHP) includes drive losses. Performance ratings do not include the effects of appurtenances in the airstream. Underlined figures indicate maximum static efficiency.

Appendix B - List of DOE-2 Keywords and Values Used for the Analysis

	FAN					COOLING COIL				COOLING CONTROL					HEATING	CHW LOOP	CHW PUMP	ZONE
DOE-2 Keyword	FAN-EIR-FPLR	SUPPLY-MECH-EFF	SUPPLY-EFF	SUPPLY-STATIC	SUPPLY-FLOW	COOLING-CAPACITY	COOL-SH-CAP	CHW-COIL-DT	CHW-COIL-HEAD	COOL-CONTROL	COOL-RESET-SCH	RESET-PRIORITY	MIN-SUPPLY-T	COOL-SET-T	ZONE-HEAT-SOURCE	COOL-SETPT-T	HEAD	MIN-CFM-RATIO
DOE-2 VSD	DOE-2 VSD	0.72	0.63															
Monitored	Monitored Fans	0.6	0.54															
660 CPL-A	660- CPL-A	0.61	0.55	4.0	145,000													
600 CPL-A	600 CPL-A	0.55	0.49															
490 CPL-A	490 CPL-A	0.42	0.37															
VAB 54	VAB 54	0.49	0.44															
0+Cooling Coil Bypass	660- CPL-A	0.58	0.52	3.3														
Cooling Coil 1	660- CPL-A	0.64	0.58	4.98		4.04E+06	3.91E+06		30								106.8	
Cooling Coil 2	660- CPL-A	0.56	0.5	3.68		4.06E+06	3.92E+06		6.75								83.55	
Cooling Coil 3	660- CPL-A	0.56	0.5	3.66		4.15E+06	3.92E+06		17.34								94.14	
Cooling Coil 4	660- CPL-A	0.55	0.5	3.51		4.22E+06	3.93E+06		10.79								87.59	
Cooling Coil 5	660- CPL-A	0.55	0.5	3.52		4.08E+06	3.91E+06		4.05								80.85	
2+Duct Sizing 1 SP 3.0				3.0														
2+Duct Sizing 1 SP 3.5				3.5														
2+Duct Sizing 1 SP 4.5				4.5														
2+Duct Sizing 1 SP 5.0				5.0														

	FAN					COOLING COIL				COOLING CONTROL					HEATING	CHW LOOP	CHW PUMP	ZONE
Keyword	FAN-EIR-FPLR	SUPPLY-MECH-EFF	SUPPLY-EFF	SUPPLY-STATIC	SUPPLY-FLOW	COOLING-CAPACITY	COOL-SH-CAP	CHW-COIL-DT	CHW-COIL-HEAD	COOL-CONTROL	COOL-RESET-SCH	RESET-PRIORITY	MIN-SUPPLY-T	COOL-SET-T	ZONE-HEAT-SOURCE	COOL-SETPT-T	HEAD	MIN-CFM-RATIO
2+SAT 1 No Reset										CONSTANT				53				
2+SAT 2 OAT Reset										RESET	Cool Reset							
(No SAT Reset)																		
2+SAT Design SAT 45				3.78	116475	4.89E+06	3.90E+06	12	30				45	45		36	106.8	
2+SAT Design SAT 47				3.83	124649	4.69E+06	3.90E+06	12.2	26.8				47	47		38	103.6	
2+SAT Design SAT 49				3.88	134057	4.43E+06	3.90E+06	12.8	21.9				49	49		40	98.7	
2+SAT Design SAT 51				3.94	145000	4.14E+06	3.91E+06	14	16.5				51	51		42	93.3	
2+SAT Design SAT 53				3.98	157889	3.90E+06	3.90E+06	14.4	14.1				53	53		44	91.2	
2+SAT Design SAT 55				4.1	173293	3.90E+06	3.90E+06	13.7	15.2				55	55		46	92	
2+SAT Design SAT 58				4.35	203000	3.90E+06	3.90E+06	12.7	17.4				58	58		49	94.2	
2+VAV Box 60%																		0.6
2+VAV Box 50%																		0.5
2+VAV Box 40%																		0.4
2+VAV Box 30%																		0.3
2+VAV Box 20%																		0.2
Elec. Reheat															Electrical			

Analysis Report
(Baseline Phase Solutions Report)

Submitted to:
New Buildings Institute
www.newbuildings.org

Integrated Energy Systems
Productivity and Building Science

On behalf of the:
California Energy Commission
Public Interest Energy Research (PIER) Program

March 27, 2003

Element 3: Integrated Design of Large Commercial HVAC Systems

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Erik Kolderup and Tianzhen Hong, Eley Associates

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The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission, annually awards up to $62 million to conduct the most promising public interest energy research by partnering with research, development and demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

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3. Renewable Energy
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5. Energy-Related Environmental Research
6. Strategic Energy Research.

This project contributes to #1 above, the PIER Buildings Program Area. For more information on the PIER Program, please visit the Commission's Web site at: www.energy.ca.gov/pier or contact the Commission's Publications Unit at 916-654-

5200. For other public reports within the *Integrated Energy Systems — Productivity and Building Science* project, please visit www.newbuildings.org/PIER

LEGAL NOTICE

TABLE OF CONTENTS

INTRODUCTION

This report presents the analysis procedures and results.

FAN SYSTEMS

Overview

This section of the report covers the analysis of fan systems including the selection and operation of the fan, motor, belts and variable speed drives. Specific issues addressed in this section include:

- Development and testing of fundamental fan system models
- Comparison of fan type and sizing
- Staging and isolation of multiple fans in parallel
- Supply pressure reset

The comparison of fan types, fan sizing, fan staging and supply pressure reset are dealt with in brief in this report. They are elaborated on in the HPAC article "A Fresh Look At Fans" (Hydeman and Stein, 2003).

Throughout this section of the report we will use the term fan system to include the fan, motor, physical drive (gears or belts) and variable speed drive (if appropriate). These components are depicted in Figure 1.

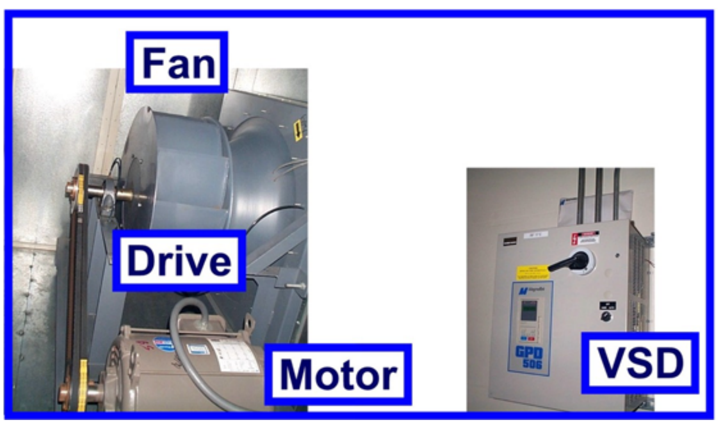


Figure 1. Fan System Components

Fan System Models

A fan system model was developed to evaluate the impact of fan selection and control on large building energy usage. For use in this project we needed a model that predicted energy usage as a function of airflow (cfm) and fan static pressure (inches of water column). We also have measured data for variable speed drive input (% speed) that we can convert to fan speed (rpm) using a correlation between the EMCS signal and tachometer readings at the fan and motor.

We sought a model that had the following characteristics:

- Accurate at predicting fan system energy over a range of full- and part-load operating conditions
- Easy to calibrate from manufacturer's or field monitored data
- Ability to identify operation in the manufacturer's "do not select" or "surge" region
- Relatively simple to integrate into existing simulation tools
- Ability to separately model the performance of the fan system components including the motor, the mechanical drive components, the unloading mechanism (e.g. VSD) and the fan.
- The model must be relatively simple to calibrate from data readily available from manufacturers.

An existing gray-box regression model presented in the ASHRAE Secondary Systems Toolkit[1] (Brandemuehl et. al, 1993) produces fan efficiency as a function of dimensionless airflow and pressure. Although this model can be readily calibrated to manufacturers data, this model does not directly work in existing simulation programs. This is due to the fact that the it correlates efficiency to a dimensionless flow term which includes both airflow and fan speed. Simulation tools like DOE2 use airflow and fan pressure as inputs to the fan system model. The fan speed can only indirectly be obtained through iteration or other mathematical solution. A second problem is that this model relies on the fan laws for extrapolation between fan wheel sizes, it does not account for the improvement of fan efficiency with wheel size that is apparent in manufacturer's data.

The existing model in DOE2 was deemed unsuitable as it does not account for the variation in the efficiency of each of the fan system components and assumes that the fan always rides on a fixed system curve.

Energy usage of a fan system is driven by the efficiency of several components: the fan, the fan belt, the motor, and possibly the variable speed drive. Each of the components has a unique characteristic that changes its efficiency as a function of fan load. Our model is composed of separate submodels for each component.

Characteristic System Curve Fan Model

We developed a gray box model based on the fan laws (referred to as the Characteristic System Curve Model). This model is based on application of the prefect fan laws for the variation of fan performance as a function of fan speed. The core assumption is that the efficiency of a fan is constant as the fan rides up and down on a particular system curve. Extensive testing with fan selection software shows this assumption appears to be true for all manufacturers fan data in both the surge and non-surge regions. For our model we defined a "characteristic system curve" as a second order equation equating fan static pressure to airflow (cfm) with zero constant and first order coefficients. A system curve

[1] We believe that this model was originally documented in the HVACSIM+ program (Clark, 1985).

is characterized by a single coefficient, which we are calling SCC (system curve coefficient). The equation for any system curve is:

$$SCC = \frac{SP}{CFM^2}$$ **(Equation 1)**

Using this assumption it is only necessary to find fan performance at a single point on a characteristic system curve to define its performance along that curve at all speeds. As depicted in Figure 2, there are 3 system curves of particular importance: the curves at the minimum and maximum ends of the tuning data set and the curve that represents the highest efficiency for the fan. As described below and depicted in Figure 5 fans behave very differently at each side of this peak efficiency. For plenum fans the "do not select" or surge line is the same as this line of peak efficiency. For all other fans it appears to be to the left of this peak efficiency line.

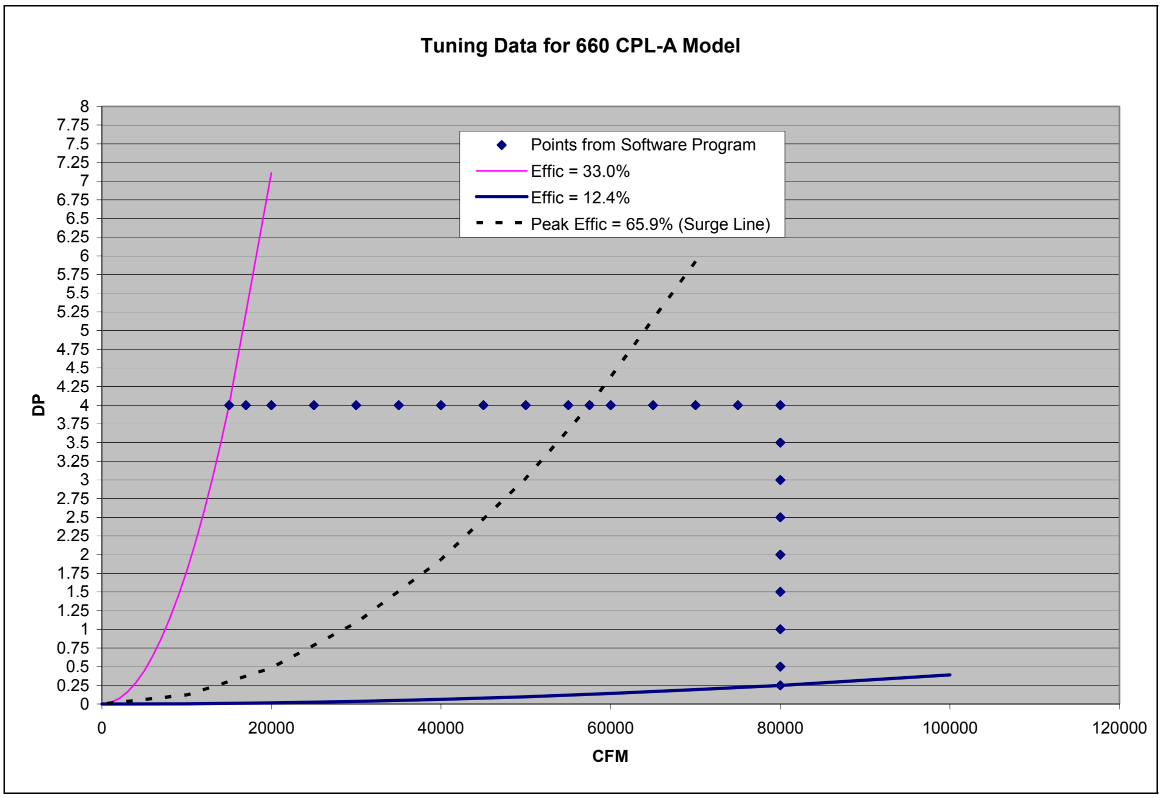


Figure 2. Tuning Data for 660 CPL-A Characteristic System Curve Model

Figure 2 shows several points of data for a particular Cook fan with system curves drawn through three of the points: two extreme points and a point on the system curve of highest efficiency. These points were all taken from the Cook selection software. The efficiency is calculated from the BHP reported by the software and using the equation:

$$FanEffic = \frac{CFM * DP}{6350 * BHP}$$ **(Equation 2)**

The model can be used to predict the fan power for any point whose system curve is between the two extreme system curves. Figure 3 is the same data as Figure 2 but overlaid on top of the fan curve from the Cook catalog. Notice that our surge line is almost exactly on top of the manufacturer's "Do Not Select" line.

When a fan enters the surge (a.k.a stall or pulsation) region not only does the efficiency drop but the fan begins to vibrate which creates audible noise and vibrations that can damage the fan, bearings, drive and attached ductwork. The further the fan moves into the surge region the greater the vibration. Catastrophic failure can occur if the fan moves well into the surge region at high power (high static). Some manufacturers appear to be more conservative than others in terms of what amount of vibration is acceptable. Moving into the surge region at low power (low static) is not likely to cause catastrophic failure or unacceptable vibration but it will reduce fan life. From our experience, fans with variable speed drives commonly operate for extended periods of time in the surge region, but it is usually at low power.

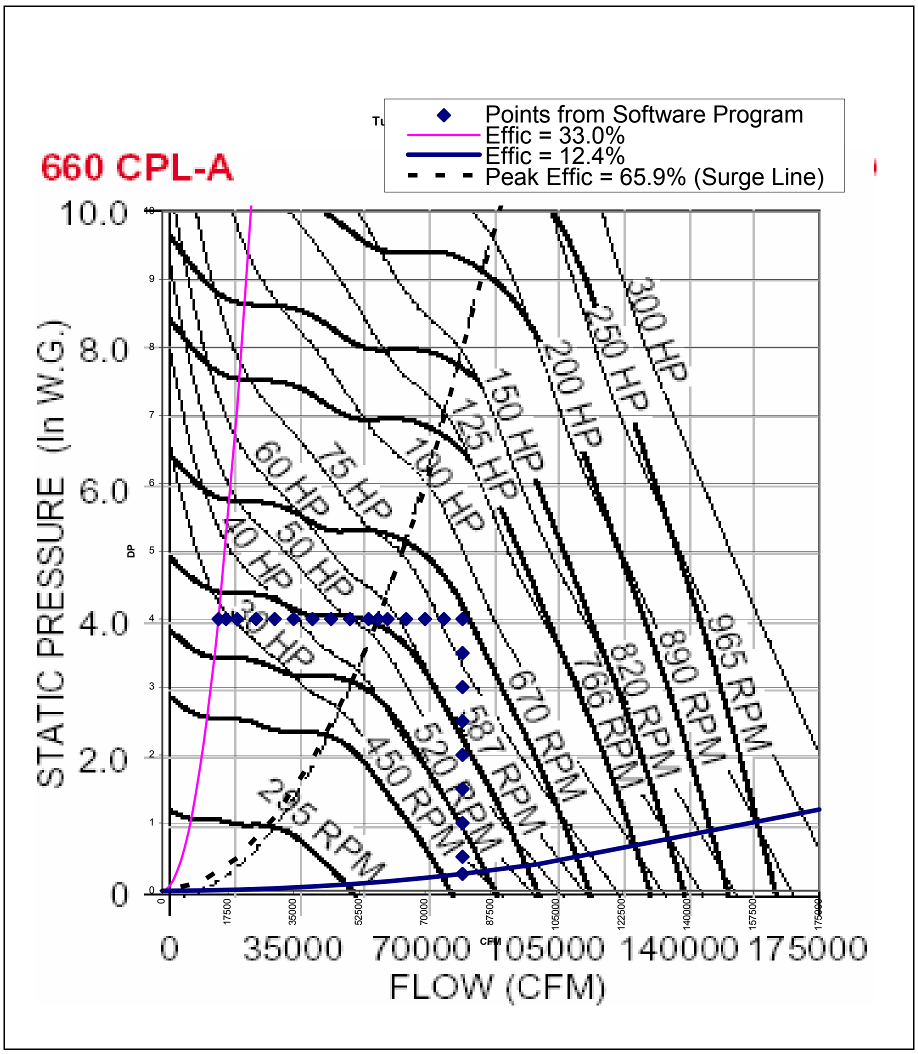


Figure 3 Tuning Data for Characteristic System Curve Model on Top of Manufacturer's Fan Curve

Figure 4 shows fan efficiency plotted against system curve coefficient (SCC) for this data. If we divide the data into surge and non-surge regions then we can fit a polynomial function to each side of the data. These equations can accurately predict the efficiency in each region.

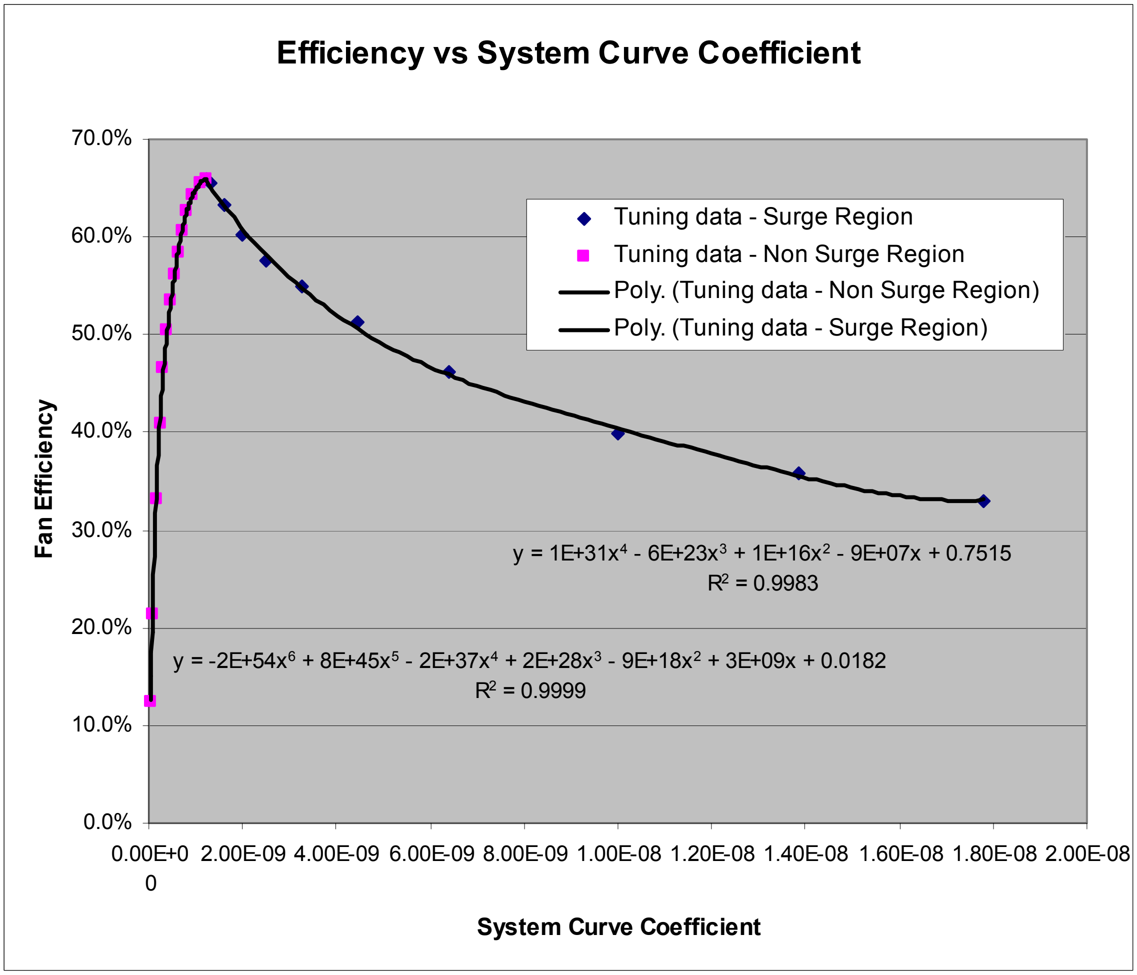


Figure 4. Fan Efficiency vs System Curve Coefficient

The efficiency curve is easier to visualize and to fit a regression equation if plotted as a function of the negative of the log of the system curve coefficient (see Figure 5). The log causes the efficiency curves to become nearly straight lines and the negative plots flips the surge and normal regions so that it matches manufacturer's curves (i.e. surge to the left, normal operation to the right). The base of the log does not seem to make much difference. We use base 10 but other bases such as base "e" (natural log) also seem to work well. We arbitrarily selected the name "Gamma" for the negative of the log of the system curve coefficient.

$$Gamma = -\log(SCC) \qquad \text{(Equation 3)}$$

Critical Gamma is the gamma that corresponds to the system curve of highest fan efficiency. One way to confirm the Critical Gamma is by trial and error using the manufacturer's software by comparing efficiency as you select points in the vicinity of the Critical Gamma. For a particular fan, any gamma value less than the Critical Gamma is in surge and any gamma greater than the critical gamma is in the non-surge region.

Fan efficiency can be very accurately predicted as a function of gamma. The most accurate prediction comes from breaking the function into two parts: an equation for gammas in the surge region and another for gammas in the non-surge region. A polynomial fits the data nicely. A first order (i.e. linear) is reasonably accurate but a third order appears to provide the best balance between fit and rational function behavior between calibrating data points. While breaking the function into two parts is the most accurate, a single equation can actually predict both the surge and non-surge regions fairly well. Figure 5 shows the R-square term for both natural log and log10 regressions of various orders for a particular fan in both the surge and non-surge regions.

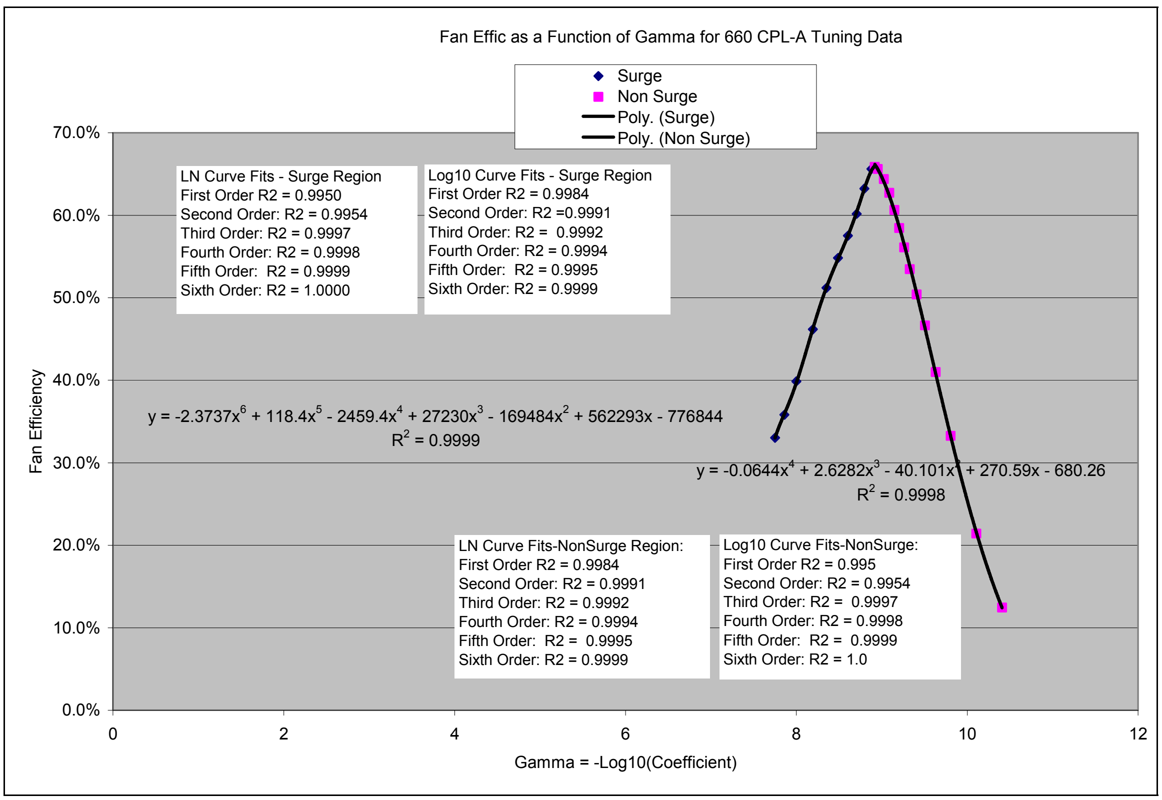


Figure 5. Fan Efficiency as a Function of Gamma

Figure 6 shows the accuracy of the Characteristic System Curve Fan model. This particular model is based on 6^{th} order polynomials of gamma with separate equations in the surge and non-surge region. Table 1 depicts the fit results of 3^{rd} order polynomials across a range of manufacturers and fan types (plenum and housed, airfoil, forward curved and backwardly inclined).

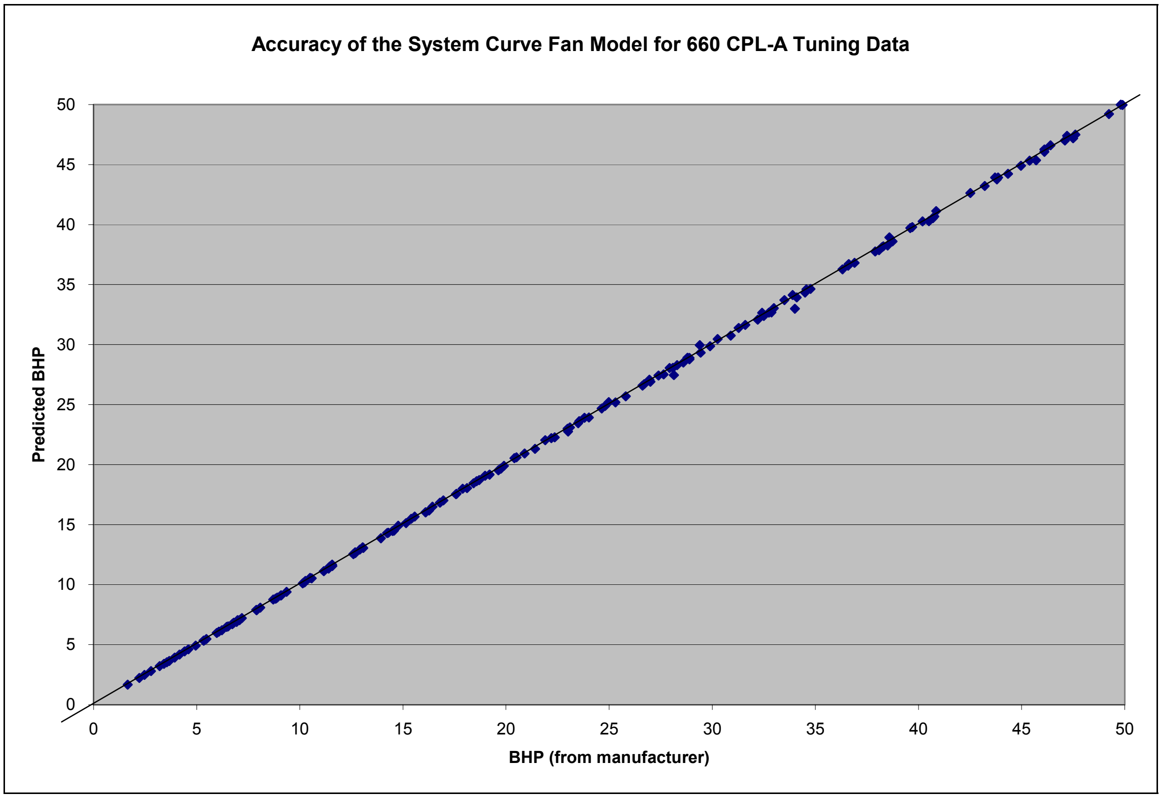


Figure 6. Accuracy of Characteristic System Curve Fan Model

Table 1. Fit Results for 43 Fans

	Left Region			Right Region		
Count	Min	Max	Average	Min	Max	Average
43	0.0%	5.7%	0.5%	0.1%	3.7%	1.7%

Figure 7 below depicts the predicted fan efficiency from the Gamma model for a plenum fan. The predicted efficiency is plotted on the Z-axis as a function of the airflow (cfm, X-axis) and fan static pressure ("H_2O, Y-axis). The efficiency is computed between the minimum and maximum characteristic system curves.

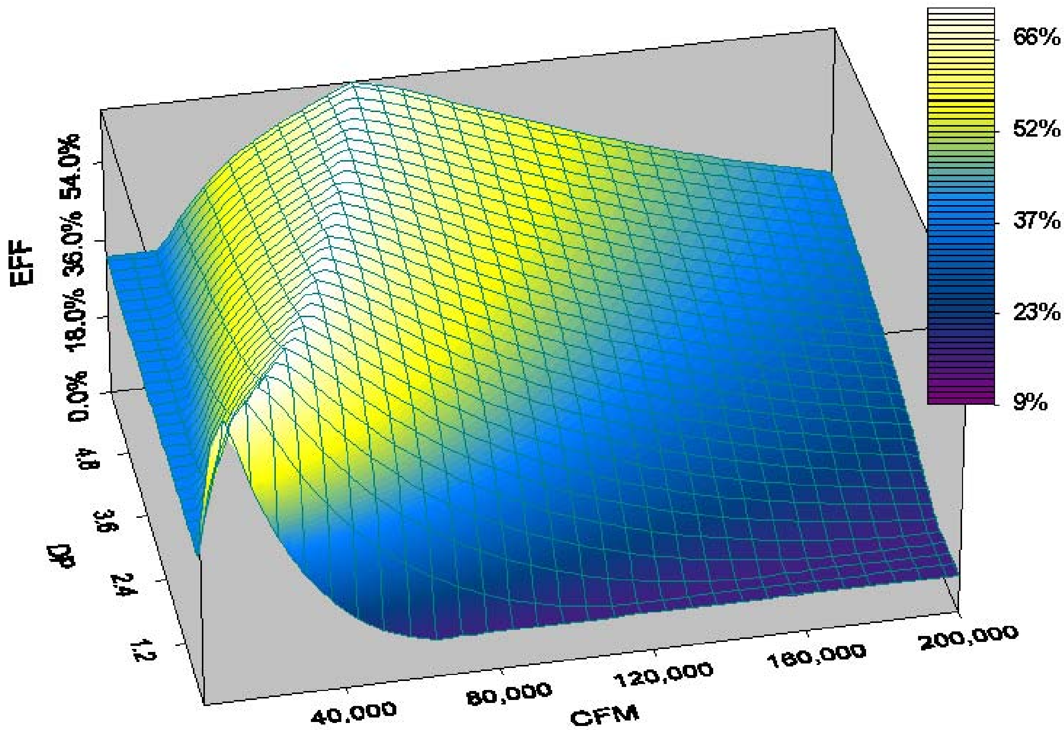


Figure 7. Cook 660 CPL-A Plenum Fan Efficiency Map Using the Gamma Model

Extending the Characteristic System Curve Model to Multiple Diameters.

ASHRAE Standard 51/AMCA Standard 210 (ASHRAE, 1999) specifies the procedures and test setups that fan manufacturers use to test fans. Manufacturers are not required to test all fan sizes. According to the standard, test information on a single fan may be used to extrapolate the performance of larger fans that are geometrically similar using the perfect fan laws. The following formulas are used to extrapolate performance:

$$CFM_1 = CFM_2 \times \left(\frac{D_1}{D_2} \right)^3$$ **(Equation 4)**

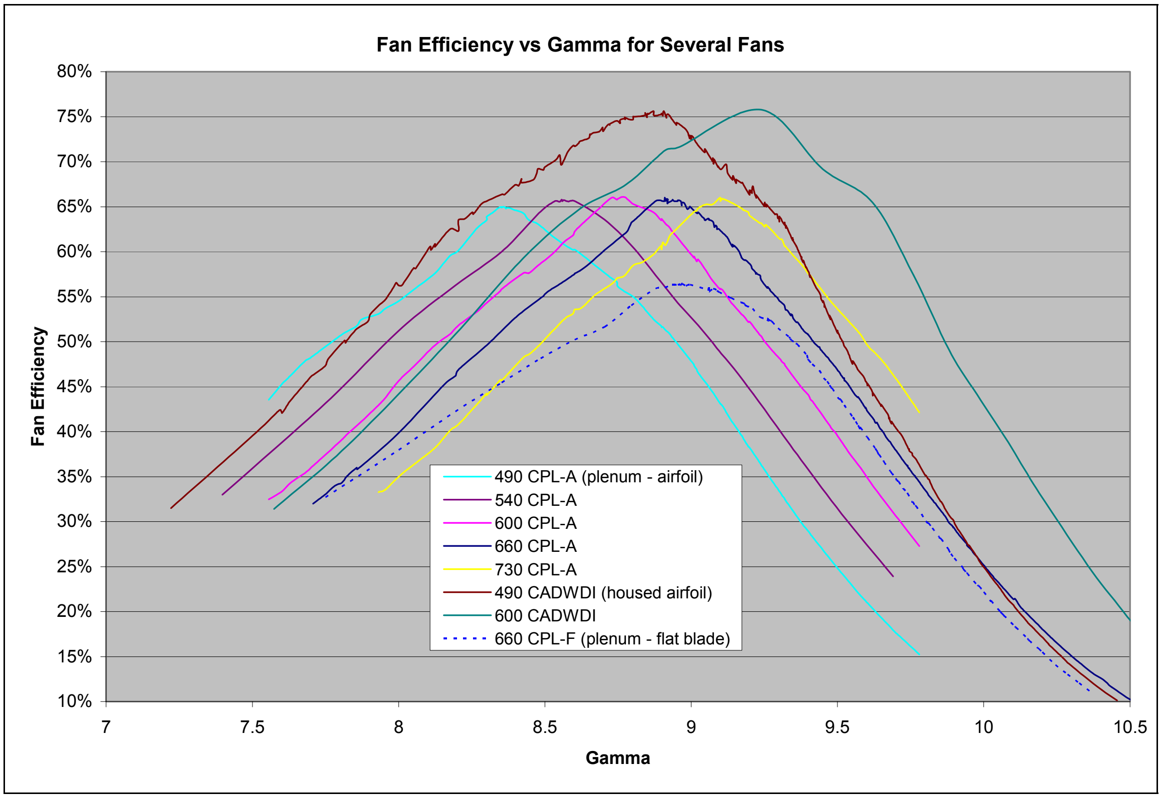
$$TP_1 = TP_2 \times \left(\frac{D_1}{D_2} \right)^2$$ **(Equation 5)**

$$SP_1 = SP_2 \times \left(\frac{D_1}{D_2} \right)^2$$ **(Equation 6)**

$$BHP_1 = BHP_2 \times \left(\frac{D_1}{D_2} \right)^5$$ **(Equation 7)**

Figure 8 shows gamma curves for several fans including 5 sizes of Cook CPL-A plenum airfoil fans. The 54 to 73 inch diameter CPL-A fans have virtually identical curves, just shifted along the x-axis, but the 49" version has a different peak efficiency and curve shape. This suggests that Cook tested the 54" fan and extrapolated the performance to the 60 to 73" sizes. Figure 8 also shows housed fans (CADWDI) and a flat blade plenum fan (CPL-F). Each fan type has a unique curve shape but a single curve shape might be used for multiple fans.

Figure 8. Fan Efficiency vs Gamma for Several Cook Fans



We believe that fan curves could be shifted and scaled as follows:

1. For each fan type develop a gamma model from a single fan using manufacturer's data.

2. Use the fan laws (Equations 4 to 7) to recreate fan curves for fans of other diameters in that product line.

3. Provide an efficiency offset for peak efficiency.

Motor Model

The next component for a fan system is the motor. We borrowed a model from the Department of Energy's Motor Challenge market transformation program (http://www.oit.doe.gov/bestpractices/motors/). This model was presented to us by Gil McCoy of Washington State University. In this model the efficiency of any motor consists of a rated efficiency at nominal motor horsepower (MHP) and a part load function for efficiency as a function of percent load that is defined as follows:

$$\%Load = \frac{BHP}{MHP_{nominal}} \qquad \textbf{(Equation 8)}$$

Note that the percent load does not correlate to the percent speed (one might expect it to be a cube law relationship) because air profiles do not follow a single system curve. Thus the percent speed for a fan with static pressure reset will produce a lower percent load than the same percent speed for a fan with fixed static pressure setpoint (i.e. one operating at a higher pressure for the same airflow).

Motor efficiency data can be found in the Department of Energy's MotorMaster+ program (http://mm3.energy.wsu.edu/mmplus/default.stm). This program has a database of hundreds of motors from a range of manufacturers. Each motor is rated at full load, 75% load, 50% load and 25% load. The same data is also available from Oak Ridge National Laboratory's Pumping System Assessment Tool (http://public.ornl.gov/psat/). The MotorMaster+ data can be fit using two equations: a 3th order polynomial from 25% to 100%MHP and the following function from 0 to 25%MHP:

$$MotorEfficiency_{0-25\%} = \frac{BHP}{BHP + FixedLosses} \qquad \textbf{(Equation 9)}$$

Where fixed losses are calculated from motor efficiency at 25%:

$$FixedLosses = \frac{0.25 * MHP}{\text{Effic}_{25\%}} - 0.25 * \text{MHP} \qquad \textbf{(Equation 10)}$$

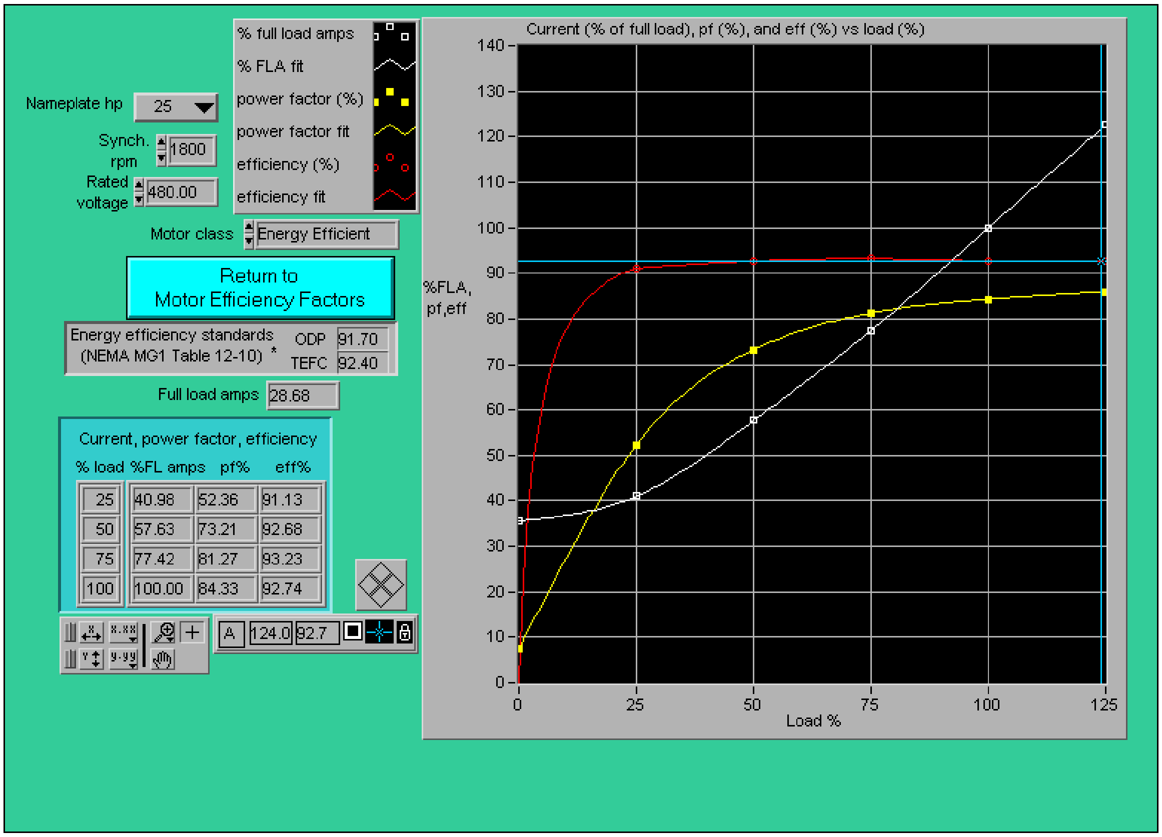


Figure 9. Sample Motor Data from PSAT Software

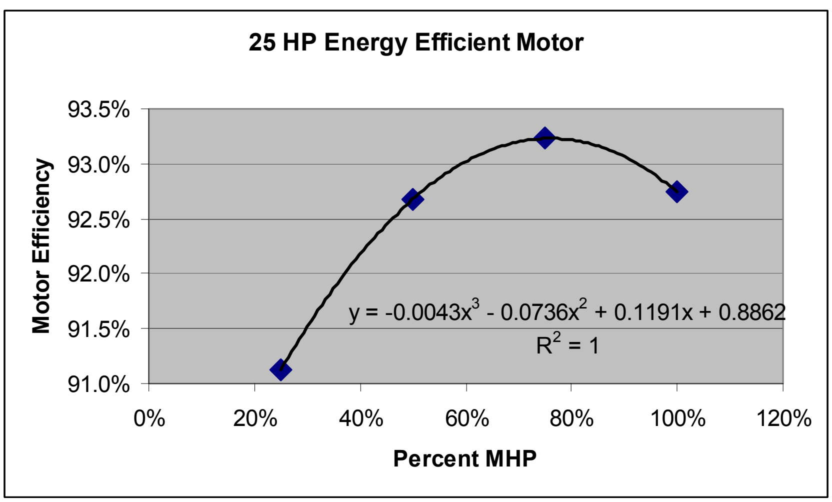


Figure 10. Example Motor Efficiency as a Function of Load

Variable Speed Drive Model

The variable speed drive model is a 3rd order equation of percent load. The calculation of percent load is done in the following steps:

1. The fan speed at the current cfm and fan static pressure is calculated from a Secondary Toolkit fan model (Brandemuehl et. al, 1993) solving for the dimensionless flow coefficient from the fan efficiency.
2. If this speed is above the minimum speed, the percent load is calculated directly.
3. If this speed is below the minimum speed, the fan, motor and belt are recalculated at the minimum speed with the static pressure adjusted for the fan riding its curve. The percent load is than calculated
4. The VSD energy is calculated from the percent load from either step 2 or 3 above.

RPM Model

Using the Secondary Toolkit fan model, RPM is calculated from phi, the dimensionless flow coefficient in two steps. First PHI is calculated from fan efficiency using two 3rd order equations for above and below the peak efficiency point. Second, RPM is calculated from PHI as follows:

$$RPM = \frac{CFM}{Phi * Diameter^3}$$, where Diameter is in feet **(Equation 11)**

The tuning data from the manufacturer is used to develop equations for phi as a function of fan efficiency. These equations can then be used, along with the output of the Characteristic System Curve Fan Model, to predict Phi and RPM for any operating condition in the tuning range.

In order to develop equations for phi as a function of fan efficiency, the fan efficiency tuning data must be divided into two regions: left and right of peak efficiency. For the data we analyzed a 3rd order polynomial fit both regions well. Figure 11 shows the equations developed for phi as a function of fan efficiency in the surge and non-surge regions for the 660 CPL-A tuning data. This figure also shows that the relationship between phi and fan efficiency is identical for the 600 CPL-A.

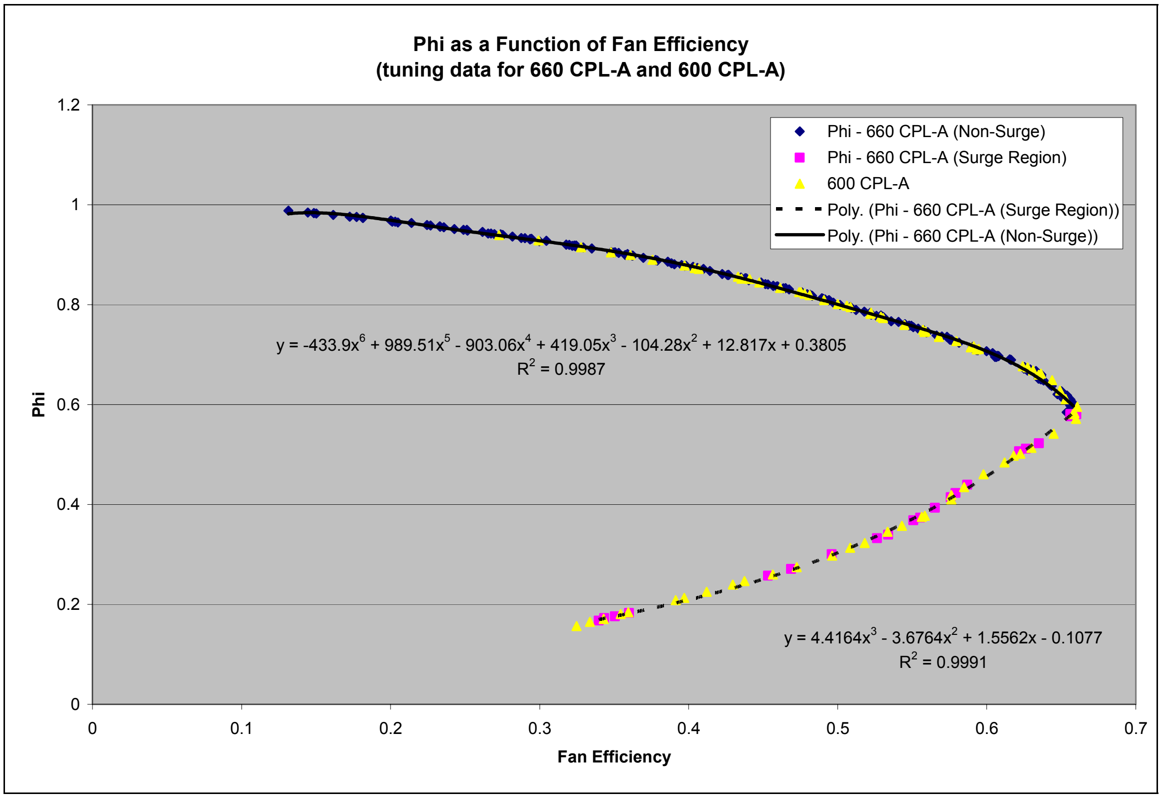
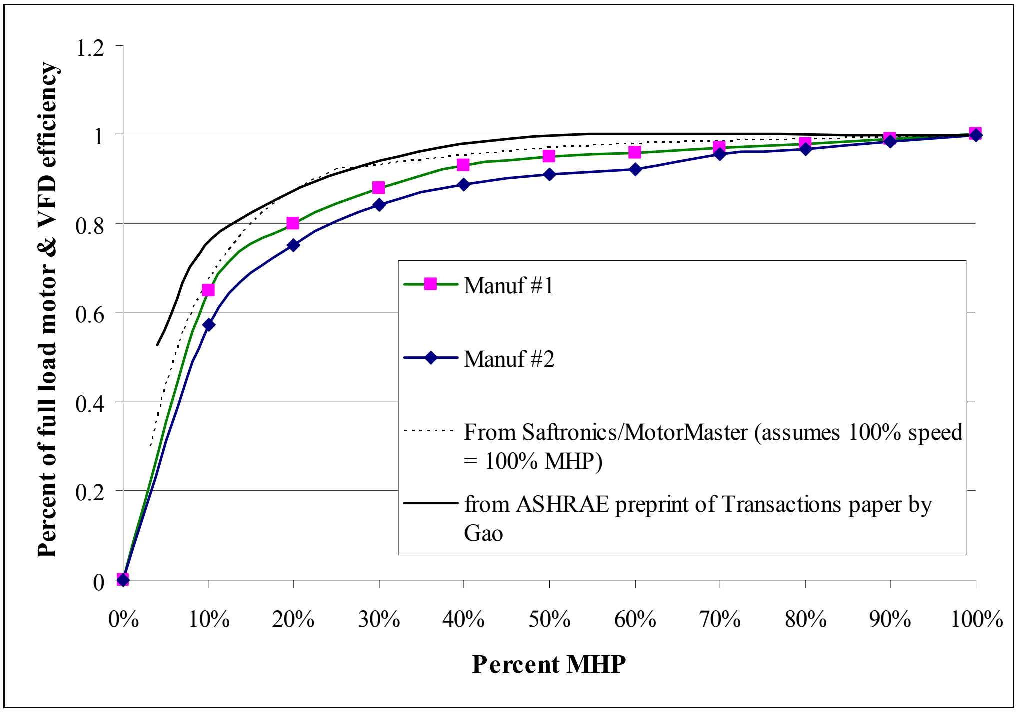


Figure 11. Phi as a Function of Fan Efficiency

Variable Speed Drive Model

Gilbert McCoy, at Washington State University, provided VSD performance data to Taylor Engineering that he received from Saftronics, a VSD manufacturer (see Appendix A). The combined efficiency of the MotorMaster/Saftronics data is reasonably consistent with similar data provided by ABB (another manufacturer) and data in an ASHRAE paper by researchers at the University of Alabama (Gao et. al, 2001 see Figure 12).

Figure 12. Combined Motor and Drive Efficiency Data from Four Sources



Belt Model

According to AMCA Publication 203-90 (AMCA, 1990), drive loss is a function of motor output (i.e. depends only on the BHP and not on the MHP). This is depicted in Figure 13 below.

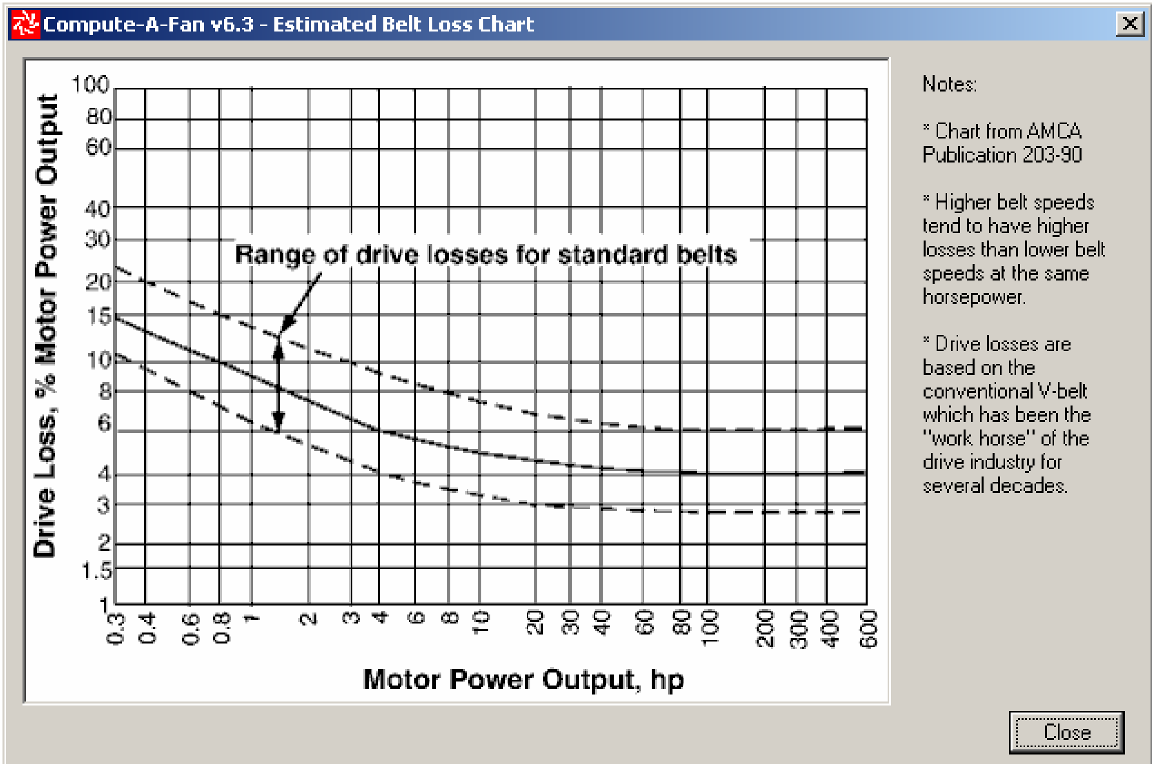


Figure 13. AMCA Belt Losses Data

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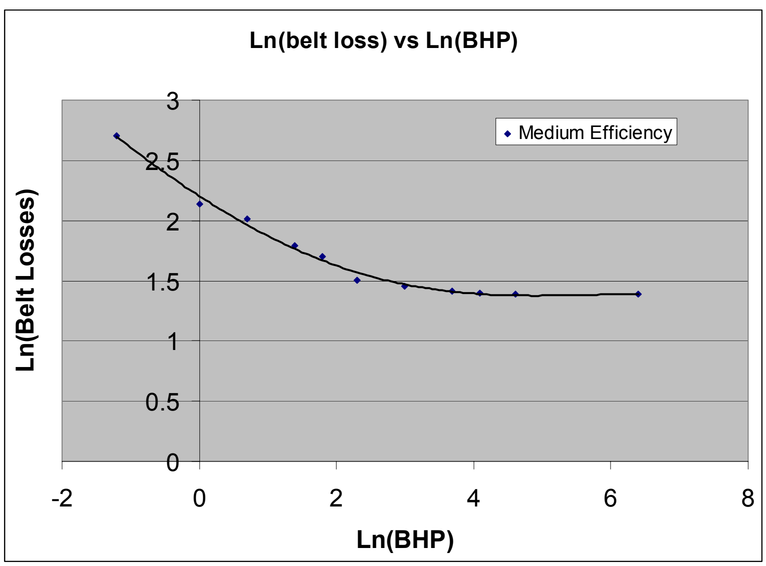

Figure 14. AMCA Belt Losses Data

Here is an approximation of the AMCA data:

Table 2. Approximate Belt Loss E

	< 0.3 BHP	0.3 to 100 BHP	>100 BHP
High Effic (low loss belts)	92%		97.2%
Med Effic	89%		96%
Low Effic (high losses)	84%		94%

In the absence of any information on the type or quality of the belts, we have been assuming medium efficiency belts for our fan scenario analyses. Tom Webster has done some field research on belt efficiency at the NBI PIER sites and is also finding that medium efficiency belts is a reasonable assumption.

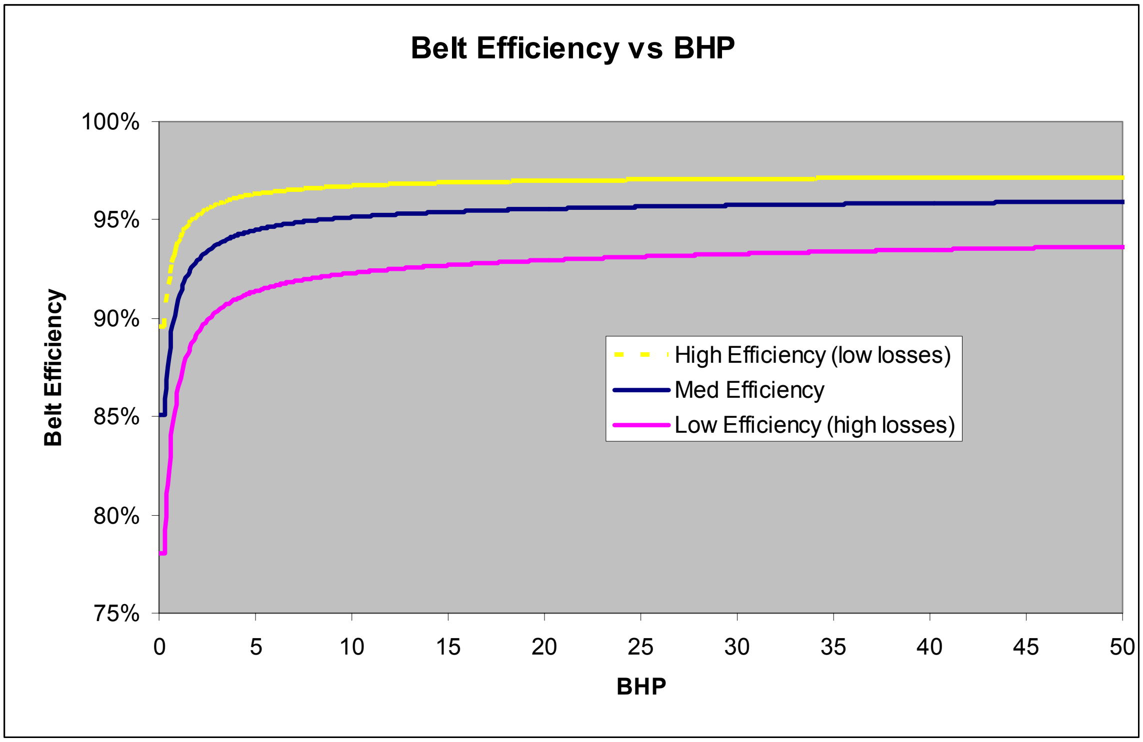

Figure 15. Belt Efficiency Functions

Fan Type and Sizing

Comparison of fan types and sizes is relatively easy. For each fan we produce a Characteristic Curve fan model as described above. Each of these fans is run across the measured cfm and static pressure. To neutralize the inherent error in predicting energy use the base case staging is modeled as well (as opposed to using the measure fan energy).

To compare classes of fans (like housed vs plenum) we can add a fixed amount of pressure to the pressure for each individual fan at a given hour.

Fan Staging and Isolation

Fan staging is handled by comparing the operation of all available fans at a given record and selecting the combination that is the most efficient.

Fixed losses for isolation devices such as inlet backdraft dampers or outlet isolation dampers can be added a fan specific pressure at each record. This is the same feature used for housed fans under type and sizing.

Supply Pressure Reset

Supply pressure reset is achieved by mapping each cfm to a system curve representing the amount and degree of reset. The system pressure is then read from the curve and used for the calculation of fan energy.

COILS

Coil Sizing

Coil sizing is achieved in a two step process. In the first step a manufacturer's program is used to select one or more larger face area coils with the same design conditions as the installed coil. The resulting air-side pressure drop savings are discounted from the measured fan pressure drop with a quadratic degradation factor with airflow.

Coil Bypass Dampers

This is similar to coil sizing except that the pressure drop credit is only applied when the economizer is in operation and providing 100% OSA.

TERMINAL UNITS

Terminal Unit Sizing

VAV Box sizing is a tradeoff between central fan energy and reheat energy. The larger a VAV box is, the lower its design static pressure. However the larger that a VAV box is the higher cfm it can control to at minimum position. This minimum position setting directly impacts reheat energy and central fan energy through airflow demand.

Using DOE-2 we will simulate a typical office building with VAV reheat. We will vary the box minimums and the main fan static pressure in order to determine the optimal box sizes that provide the lowest total energy cost (i.e. the tradeoff between fan energy and reheat energy). The goal is develop some rules of thumb for VAV box sizing in terms of the maximum total pressure drop across the box at design conditions.

Base Case Model

Building Envelope

1. 5 story, 50,000 sf square building. (We will want to have many zones, so we may not want to use a floor multiplier. See loads schedules below. 5 zones per floor times 5 floor should be sufficient)
2. 7 foot high continuous glazing, double pane, low-e glass
3. 12 foot deep perimeter zones

Climate

Two Runs: Zone 3 (Bay Area) and Zone 12 (Sacramento)

Internal Loads

1. Lighting power density: 1.5 W/ft2
2. Equipment power density: 2.0 W/ft2
3. Occupancy density: 100 ft2/ person

Load Schedules

We will need to have many different schedules in different zones in order to capture the effect of reheat at low load. For simplicity we will use the same schedule for lights, people, and equipment. We should have at least 3 schedule types:

1. High occupancy– variable load with average of 65% during 8am-6pm weekdays.
2. Medium occupancy – variable load with average of 45% during 8am-6pm weekdays.
3. Low occupancy – variable load with average of 25% during 8am-6pm weekdays.

Each schedule should be dithered so that there are 2 or 3 variations of each throughout the 25 total zones.

Fan Schedule

5 am – 7 pm

Thermostat setpoints

72°F cooling, 70°F heating

Design Air Flow

Loads calcs will be run in Trace or HAP. For each climate zone we will come up with a CFM/ft2 for each orientation. These air flows will then be multiplied by the zone areas used in DOE-2. DOE-2 Keyword: ASSIGNED-CFM

Orientation	Design Flow Rate (CFM/ft2)	Design Flow Rate (CFM/ft2)
	CZ03	CZ12
North	??	??
South	??	??
East	??	??
West	??	??
Interior	??	(Same as CZ03)

Zone Properties

4. THERMOSTAT-TYPE: Reverse Action. For VAV systems, this Thermostat Type behaves like a dual maximum thermostat, it allows the air flow rate to rise above the minimum design heating air flow rate (i.e., the Minimum Flow Ratio).
5. THROTTLING-RANGE: 4 °F (DOE-2 says : Warning--For a VAV system, the Throttling Range should be at least 4 to 6 °F (to reflect reality and to prevent instability in the simulation)).
6. MIN-FLOW-RATIO: Unfortunately DOE-2 does not allow us to specify both MIN-FLOW-RATIO and MIN-CFM/SQFT. Therefore, we will specify MIN-FLOW-RATIO as a user defined expression: Max(Turndown, VentMin), where:
   - BoxTurndown is a function of the Parametric Run
   - VentMin = 0.15*Design Flow Rate for this zone (e.g. 3 CFM/ft2)

System Properties

7. VAV reheat, one air handler for the building
8. Supply Fan efficiency : 70% (this includes motor, belt and drive efficiency)
9. Fan EIRFPLR curves developed for both fixed 1.5" static pressure setpoint and perfect reset.

10. SUPPLY-STATIC: 3.5 + "BTP." BTP is the Box Total Pressure. It will vary depending on the parametric run.

11. FAN-CONTROL: VARIABLE SPEED. (We could also set it to Fan Electric Input Ratio FPLR and put in our own curve)

12. Motor efficiency: 100% (Motor and drive efficiency will be modeled in the fan curve and peak efficiency)

13. Coil and fan capacity: autosize

14. MIN-SUPPLY-T: 57

15. COOL-CONTROL: CONSTANT

16. Drybulb economizer

17. No return fan

18. MAX-SUPPLY-T: 110°F (i.e., the highest allowable diffuser air temperature).

Plant Properties

1. Water-cooled chilled water plant – default efficiencies
2. Default HW boiler

Utility Rates

- PG&E E-20s
- PG&E GNR1

Parametric Runs

We will generate parametric runs for each simulation. Turndown is calculated using the methodology described in the spreadsheet "VAV Box Sizing.xls" Basically, we iterate on the Box CFM (using the box manufacturer's software for SP and hand calc for VP) until the total pressure matches the target, then take an average between the best and worst turndown across all box sizes.

Run ID	Box Total Pressure (inches)	Turndown
0	0.3	To be determined
1	0.4	To be determined
2	0.5	10%
3	0.6	To be determined
4	0.7	To be determined
5	0.8	To be determined

Sensitivity Analyses

We will also simulate each of the following modifications to the basecase model in both climate zones. These modifications will be run individually.

Aggressive Load Calcs

- LPD = 1.0 w/ft2
- EPD = 1.0 w/ft2
- This means new load calcs to develop new design air flows.

Highly Conservative Load Calcs

- LPD = 1.5 w/ft2
- EPD = 4.0 w/ft2
- This means new load calcs to develop new design air flows.

Low Load Schedules

Most of the zones will have low load schedules, e.g. variable load with average of 25% during 8am-6pm weekdays.

High Load Schedules

Most of the zones will have high load schedules, e.g. variable load with average of 65% during 8am-6pm weekdays.

Continuous Operation

Fan schedule of 24/7

Combinations

We may choose to simulate combinations of the above modifications depending on the results of the individual simulations.

DCV

Procedure for calculating the CO2 impact of DCV

Step 1: Find the critical zone (the one with the highest room CO2 concentration, Cr)

Step 2: Solve for the supply air concentration that would have provided 1,100 ppm at the zone

$$C_s^{'} = C_s + (1{,}100 - C_R) \qquad \textbf{(Equation 12)}$$

Note the rate of generation and derivative term in the room drops out of this equation. At the room level the balance is determined by:

$$V_S \times C_S + \dot{N} + v \times \frac{\delta C_R}{\delta t} = V_S \times C_R \qquad \textbf{(Equation 13)}$$

This assumes that there is no short circuiting between supply and return.

Step 3: Now solve for the volume of OSA that would provide the target concentration of CO2 in the supply ($C_S^{'}$)

$$V_S \times C_S = V_{OSA} \times C_{OSA} + V_{RA} \times C_{RA}$$

$$V_{OSA} = \frac{V_S \times C_S - V_{RA} \times C_{RA}}{C_S} \qquad \textbf{(Equation 14)}$$

Where from a conservation of mass we get:

$$V_S = V_{OSA} + V_{MA} \qquad \textbf{(Equation 15)}$$

If we define the term %OSA as Vosa/Vs we can solve the equation as follows:

$$\%OSA = \frac{C_S - C_{RA}}{C_{OSA} - C_{RA}} \qquad \textbf{(Equation 16)}$$

From this we can calculate the new %OSA for a target Cs, measured Cosa and specified Cr (1,100 ppm). Note this equation will have problems when all the zones are at low load as the C_{RA} approaches the C_{OSA}

We need to measure CO2 concentrations in the space, supply duct, OSA and Return Air. We could get away with not measuring the OSA or RA flow but might want to measure one for safety (a cross check). The %OSA equation is not accurate when Cosa is close to Cra (an unlikely scenario).

Step 4: Calculate the energy as the reduced load from the OSA=1.1XVosaX(Tosa-Tra). This equation calculates sensible load savings only.

Step 5: Filter the savings for when the economizer is not in operation.

INTERNAL HEAT GAIN

Introduction

Overestimates of zone cooling loads can lead to system inefficiencies caused by VAV box oversizing and possibly reduced cooling plant efficiency when operating at partial load. Overspecifying zone internal gains will result in overestimating zone cooling loads.

This analysis topic studies the monitored internal heat gains data from two sites, #1 and #4.

Lighting and Plug Loads – Site 1, Third Floor

The lighting and plug loads of the third floor of at Site #1 is monitored at 15 minute time intervals from 9/14/2001 to 8/15/2002. Loads for the server room and other office areas are monitored separately.

Statistics of Monitored Data

Table 3. Statistics of Measured Lighting and Equipment Power for Office Areas

	Max kW	Min kW	Avg. kW	Area sf	Peak W/sf	Peak Time
Equipment Power	21.96	7.62	11.91	32,628	0.67	3/21/02 12:15 PM
Lighting Power	13.94	0.00	6.28	32,628	0.43	2/28/02 11:15 AM

Table 4. Statistics of Measured Lighting and Equipment Power for Server Room

	Max kW	Min kW	Avg. kW	Area sf	W/sf
Equipment Power	45.75	0.00	42.71	1,805	25.35
Lighting Power	1.89	0.15	1.83	1,805	1.05

The server room has very constant lighting and equipment loads

Table 5. Monthly Electricity Usage of Lighting, Equipment and Building Total

Month	Bldg kWh	Office Third Floor Plug kWh	Office Third Floor Lighting kWh	Server Room Plug kWh	Server Room Lighting kWh
1	172,340	8,682	6,092	32,142	1,372
2	135,721	8,541	5,505	29,000	1,237
3	170,214	9,524	6,092	32,012	1,371
4	184,944	9,227	6,168	30,686	1,320
5	194,873	9,158	6,124	31,306	1,353
6	196,200	8,847	5,777	29,909	1,303
7	209,520	8,675	6,039	30,940	1,341
10	120,223	8,692	6,019	32,195	1,382
11	161,842	7,798	5,726	31,302	1,326
12	168,361	7,835	5,694	32,179	1,372

Comparison of Monitored Data with Design Data

The measured office area lighting power density is very low compared with normal design criteria for offices. A site visit indicated that the office area is about 60% occupied and the lighting system is controlled by occupancy sensors. The server room equipment power density is also low compared with normal design criteria, which may be partly due to the overdesign and partly due to the wide variations of server room configurations. The design data listed in the table is general and not specific to this building.

Table 6. Lighting and Plug Loads – Monitored vs Design

	Office		Server Room	
	LPD	EPD	LPD	EPD
Measured	0.43	0.67	1.05	25.4
Design*	1.2	0.81	1.2	45.0

*The design data is based on rule-of-the-thumb.

Hourly Profiles

Weekday and weekend hourly profiles of lighting and plug power for the office area without server rooms are listed in table and illustrated in figures based on measured data.

Weekday profiles show significant daily usage pattern of lighting and equipment power, while weekend profiles are flat.

Table 7. Weekday Profile of Lighting kW

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Avg	3.24	3.36	3.27	3.14	3.12	3.74	6.80	8.96	9.81	10.6	11.2	11.1
Max	8.54	7.28	7.67	6.99	3.77	7.10	9.30	11.0	12.5	13.2	13.3	13.3
Min	2.81	2.84	2.84	2.82	2.82	2.87	3.44	6.52	6.84	6.79	6.83	6.78
SD	0.60	0.52	0.65	0.45	0.16	0.41	0.53	0.57	0.82	1.03	1.15	1.10
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Avg	10.6	10.6	10.5	10.3	10.0	9.33	8.96	8.30	7.38	7.32	4.62	3.21
Max	12.3	12.5	12.6	12.5	12.1	11.2	10.6	9.98	8.41	8.04	7.27	7.03
Min	6.78	6.77	6.78	6.78	6.78	6.79	6.85	6.90	6.81	6.78	4.02	2.81
SD	0.94	0.98	1.04	0.94	0.89	0.73	0.77	0.64	0.26	0.26	0.32	0.41

Table 8. Weekday Profile of Plug kW

Hour	1	2	3	4	5	6	7	8	9	10	11	12
Avg	10.4	10.4	10.3	10.2	10.2	11.3	12.1	13.2	14.5	15.5	16.4	16.8
Max	12.7	12.4	12.3	12.3	12.3	13.3	14.6	16.5	20.8	20.5	20.6	21.2
Min	7.92	7.90	7.92	7.88	7.86	7.88	8.24	8.51	8.53	8.53	8.47	8.50
SD	1.00	1.01	1.00	0.94	0.95	1.04	1.18	1.40	1.87	1.92	2.05	2.15
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Avg	16.6	16.4	16.1	15.8	15.1	13.9	12.4	11.4	11.0	11.1	10.8	10.5
Max	21.2	20.2	20.0	19.4	18.4	16.9	15.2	14.6	13.5	13.6	13.3	12.7
Min	8.54	8.58	8.58	8.56	8.49	8.52	8.56	8.51	8.52	8.55	8.09	7.88
SD	2.08	2.00	1.96	1.91	1.75	1.51	1.23	1.01	0.94	0.97	1.03	0.99

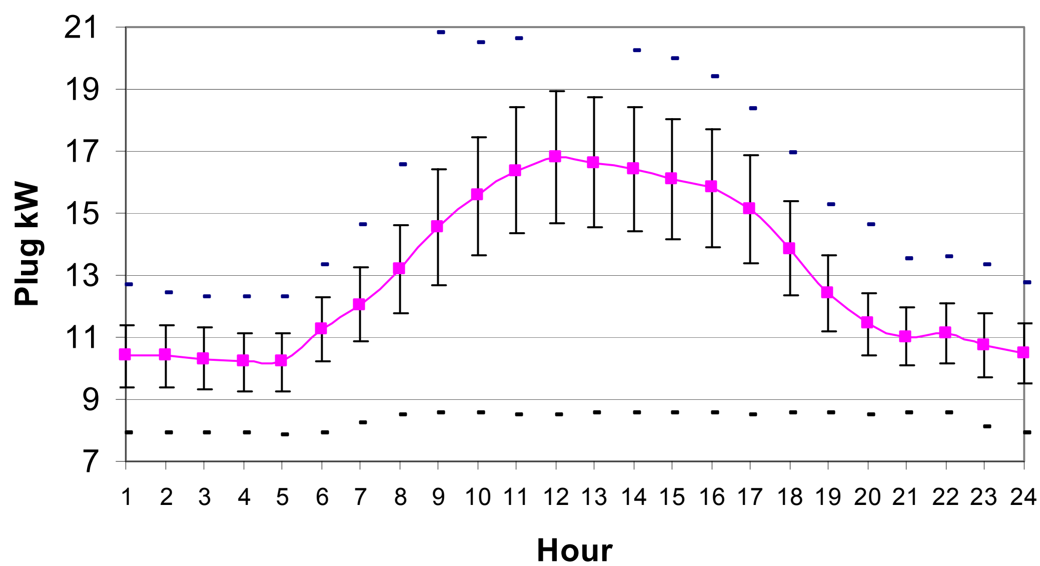

Figure 16. Weekday Profile of Plug Power
Showing Average (line), Min/Max (dashes), and Standard Deviation (error bars)

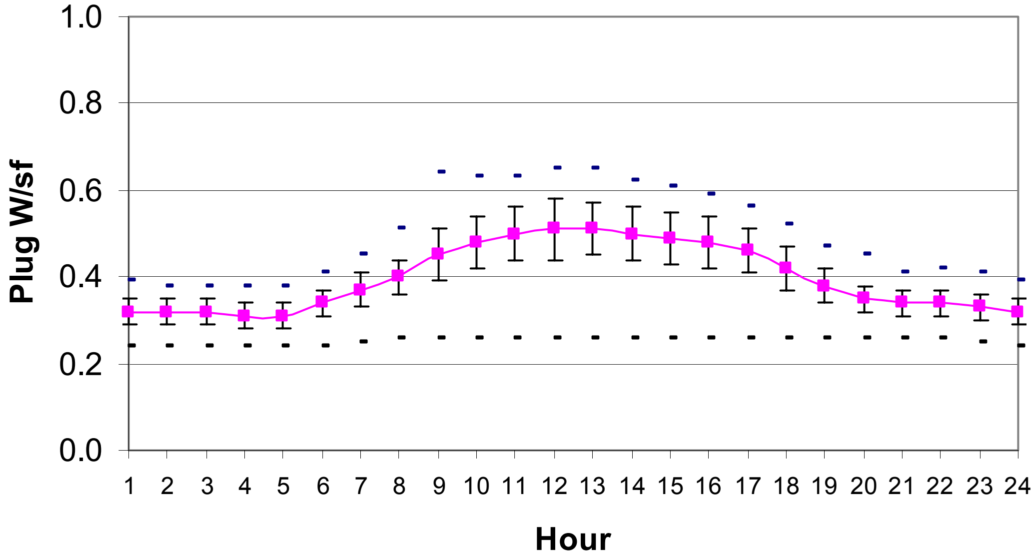

Figure 17. Weekday Profile of Plug Power Density
Showing Average (line), Min/Max (dashes), and Standard Deviation (error bars)

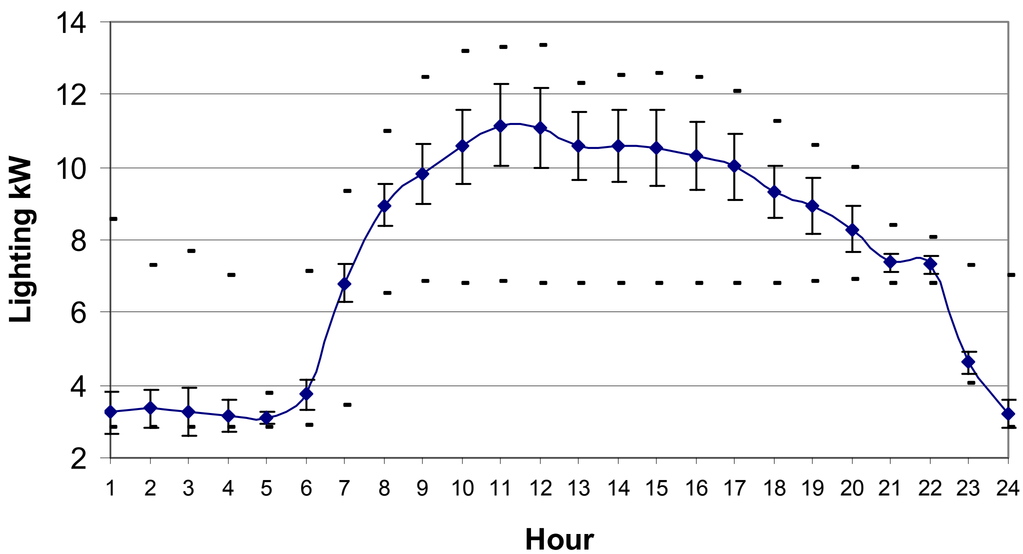

Figure 18. Weekday Profile of Lighting Power
Showing Average (line), Min/Max (dashes), and Standard Deviation (error bars)

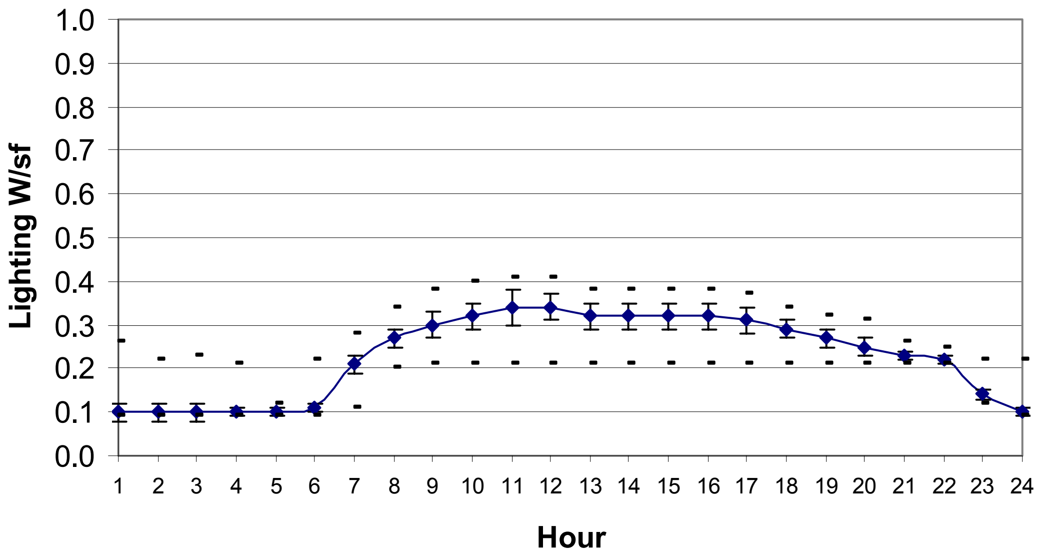

Figure 19. Weekday Profile of Lighting Power Density Showing Average (line), Min/Max (dashes), and Standard Deviation (error bars)

Table 9. Weekend Profile of Lighting kW

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Avg	3.28	3.35	3.12	3.07	3.08	3.09	3.40	3.50	3.08	3.12	3.14	3.17
Max	7.37	7.58	3.71	3.48	3.48	4.06	4.99	4.67	3.54	3.50	3.63	3.70
Min	2.81	2.86	2.82	2.82	2.82	2.81	2.82	2.82	2.80	2.80	2.80	2.78
SD	0.91	0.66	0.18	0.12	0.13	0.17	0.46	0.55	0.16	0.16	0.17	0.18
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Avg	3.25	3.35	3.40	3.39	3.41	3.55	3.57	3.57	3.59	3.65	3.33	3.28
Max	5.50	7.54	7.70	7.45	8.15	7.52	7.75	7.26	7.26	7.26	6.68	7.05
Min	2.79	2.77	2.78	2.78	2.76	2.77	2.77	2.78	2.79	2.79	2.80	2.80
SD	0.35	0.78	0.95	1.02	1.11	1.26	1.36	1.38	1.40	1.45	0.74	0.86

Table 10. Weekend Profile of Plug kW

Hour	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Avg	9.14	9.14	9.15	9.15	9.15	9.12	9.13	9.11	9.10	9.09	9.10	9.12
Max	10.7	10.6	10.7	10.8	10.7	10.6	10.6	10.7	10.9	10.6	10.7	10.7
Min	7.92	7.92	7.83	7.88	7.88	7.86	7.82	7.83	7.84	7.84	7.86	7.85
SD	0.62	0.62	0.64	0.65	0.64	0.64	0.68	0.66	0.67	0.65	0.65	0.63
Hour	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Avg	9.15	9.19	9.22	9.21	9.19	9.18	9.17	9.15	9.16	9.16	9.13	9.09
Max	11.0	11.5	11.3	11.4	11.3	11.3	11.1	11.1	11.2	11.4	10.8	10.6
Min	7.87	7.86	7.93	7.91	7.92	7.88	7.93	7.91	7.91	7.95	7.90	7.89
SD	0.65	0.68	0.67	0.66	0.65	0.66	0.64	0.65	0.64	0.67	0.63	0.61

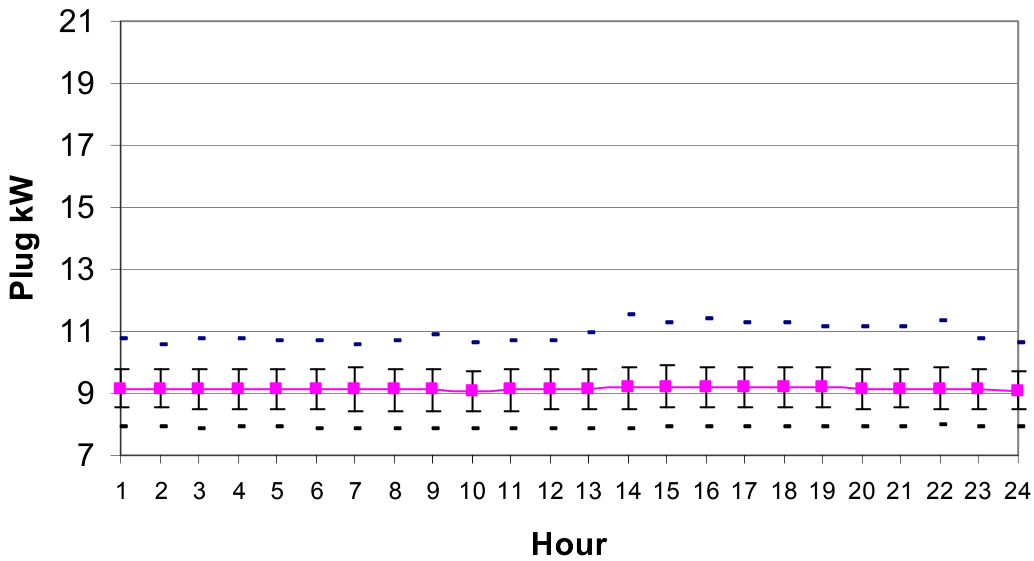

Figure 20. Weekend Profile of Plug Power
Showing Average (line), Min/Max (dashes), and Standard Deviation (error bars)

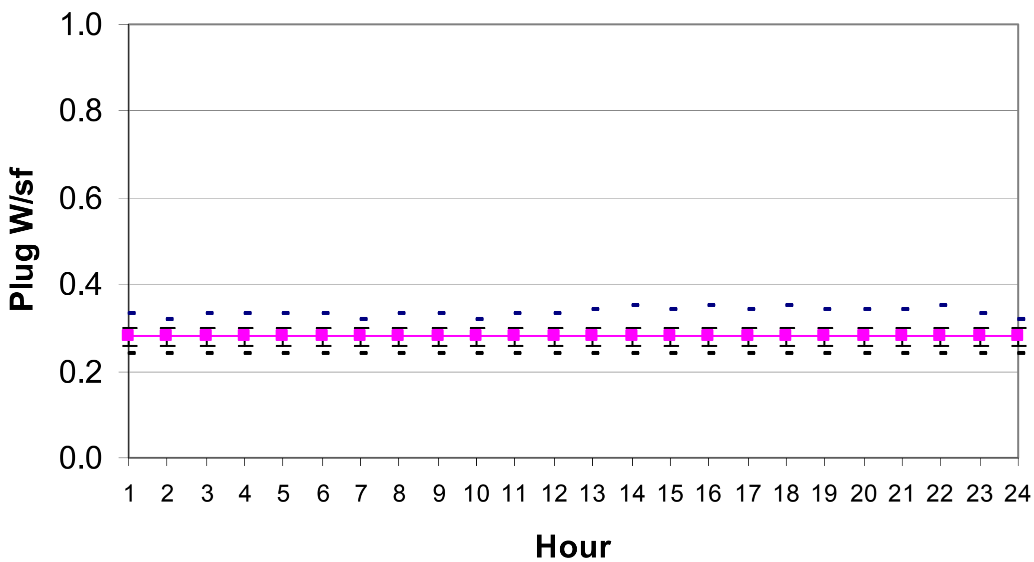

Figure 21. Weekend Profile of Plug Power Density
Showing Average (line), Min/Max (dashes), and Standard Deviation (error bars)

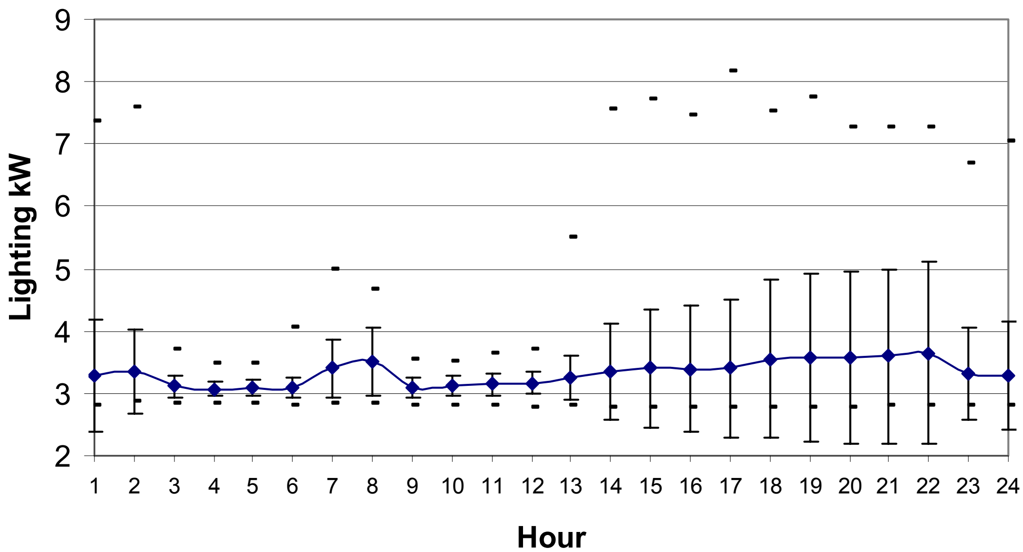

Figure 22. Weekend Profile of Lighting Power Showing Average (line), Min/Max (dashes), and Standard Deviation (error bars)

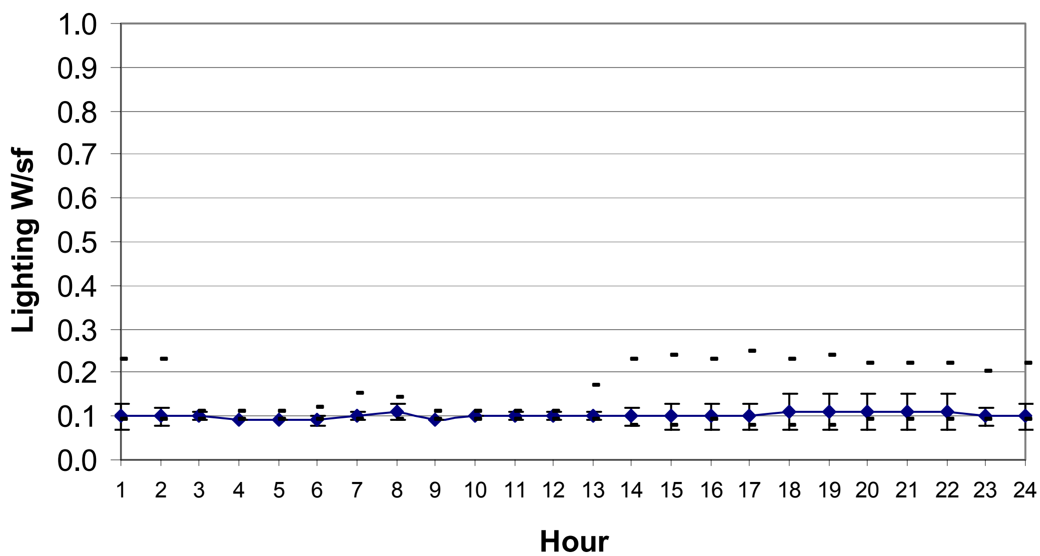

Figure 23. Weekend Profile of Lighting Power Density Showing Average (line), Min/Max (dashes), and Standard Deviation (error bars)

Cooling Loads of Internal Zones at Site 4

Based on monitored data of zone supply air flow, supply air temperature, and zone temperature, the zone cooling load is calculated for internal zones where the cooling loads mostly come from the internal loads like lighting and equipment power and occupant heat gains. These data are recorded from the building EMCS and were not calibrated to confirm accuracy. No directly monitored lighting or equipment power is available.

Measured data is from 10/18/2002 to 1/13/2003 for the interior zones on the 7th floor of Site #4.

Table 11. Comparison of VAV Box Data – Measured vs Design

VAV Box ID	Measured Max CFM	Design CFM	Measured Max Cooling Loads Btu/h	Design Cooling Loads Btu/h	Area - estimated	Measured Maximum W/sf	Design W/sf
1	1238	1200	27812	26400			
9	1409	1300	26225	28600			
16	917	900	15213	19800			
17	2061	1800	39960	39600	1250	9.4	9.3
18	568	1250	1540	27500	1120	0.4	7.2
19	1880	2000	42737	44000			
20	442	1450	8565	31900			
21	2788	1800	52430	39600			
22	642	1050	11201	23100			
23	2253	2060	60929	45320			
24	295	280	6734	6160			
25	2037	1800	42375	39600	1250	9.9	9.3
26	213	200	5054	4400			
27	296	2200	7109	48400			
28	278	2500	4920	55000			
29	1466	2400	27834	52800			
31	556	n.a.	8935	n.a.			
33	321	n.a.	6657	n.a.			

The measured maximum cooling loads is close to the design cooling loads around 9.5 W/sf for a courtroom. Figure 24 shows the time series of cooling loads in W/sf. Most of the time, the cooling loads is less than 5 to 6 W/sf, but the maximum goes to 10 W/sf. The courtroom shows a wide variation of cooling loads during a day which matches its usage pattern when sometimes there are more people in the courtroom while other times few people present.

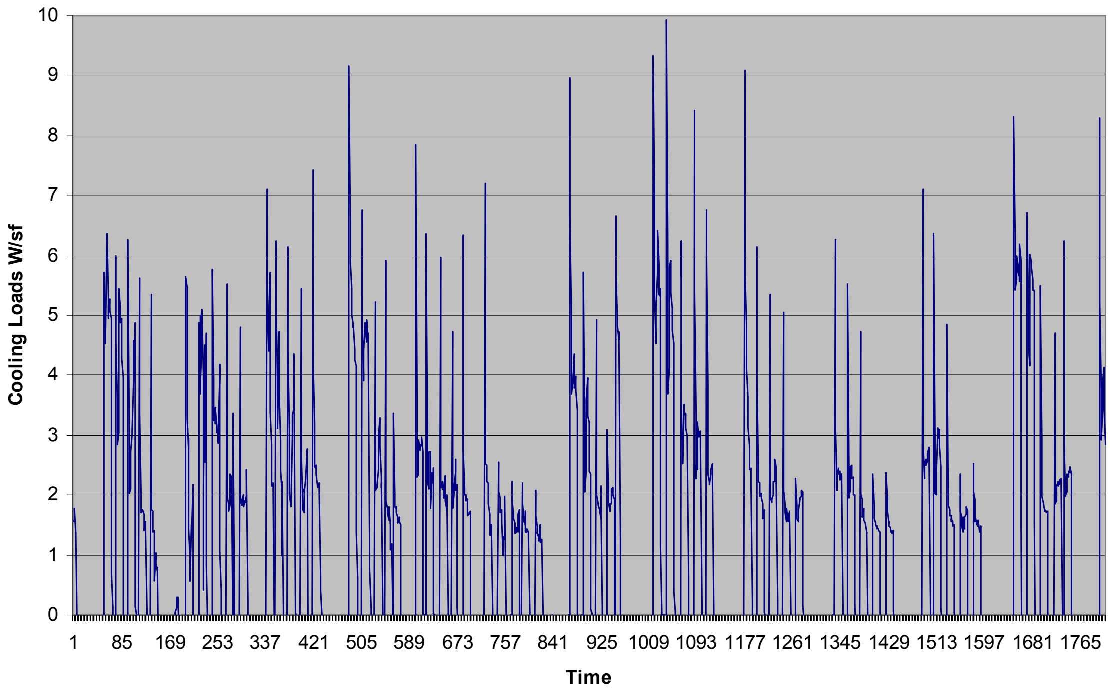

Figure 24. Courtroom cooling loads

Recommendations

Equipment nameplate power is not the actual power consumed by the equipment either at peak or part load conditions. The heat gains from internal equipment is always much less than the nameplate power.

Accurate estimation of internal heat gains is a crucial step to accurately calculate cooling loads and size HVAC equipment. When performing cooling load calculations, the peak demand and hourly use profile of internal heat gains should not be over-estimated. ASHRAE Research Project 1093-RP Compilation of Diversity Factors and Schedules for Energy and Cooling Load Calculations presents methods used to derive the diversity factors and typical hourly load shapes of lighting and receptacle loads in office buildings. In the final report the results of the analysis of data collected from databases at the Energy Systems Laboratory (ESL) and the Lawrence Berkeley National Laboratory (LBNL) are reported. The CEC web site also has information of appliance energy use.

Survey and snapshot of buildings with similar type and usage may be a good way to obtain reliable heat gains data which is better than rule-of-the-thumb watts per square foot. Operation and controls are important in determining actual hourly use.

SYSTEM EFFECTS

Introduction

Fan performance is tested in laboratories based on ideal uniform airflow profile upstream and downstream of the fan. If the airflow patterns of the fan are different from the laboratory test (and they almost always are), then there is a "system effect." System effects actually cause the fan to develop a different characteristic curve, as well as introduce additional pressure drop. They also may create pulsing, erratic and uneven system responses. These system effects are described in AMCA Publication 201 – Fans and Systems. Elbows, obstructions, swirl, and similar items cause system effects. Extensive testing has been done to develop the factors found in the publication.

Turbulence into or leaving fan causes poor performance. The system behaves as if there was extra resistance to flow. The cost is increased energy and fan wear and tear.

Site 3

There are two AHUs on the east and west side of the 16th floor serving a loop duct that feeds VAV boxes. The design condition of each is 12,000 cfm at 4 in.wc. The inlet static pressure sensor for the fan is bad.

The static pressure profile was measured for the east air handler (AHU-16E). Test conditions were 12540 cfm at 3.54 in.wc. The variable frequency drive of both supply fans are adjusted to 58.5 HZ to maintain the design static pressure of 1 in.wc and total supply air flow of 24,400 cfm. All boxes are at about 75% open. Supply air velocity is 1600 fpm, return air velocity is 700 fpm. Figure 25 shows the tested static pressure profile.

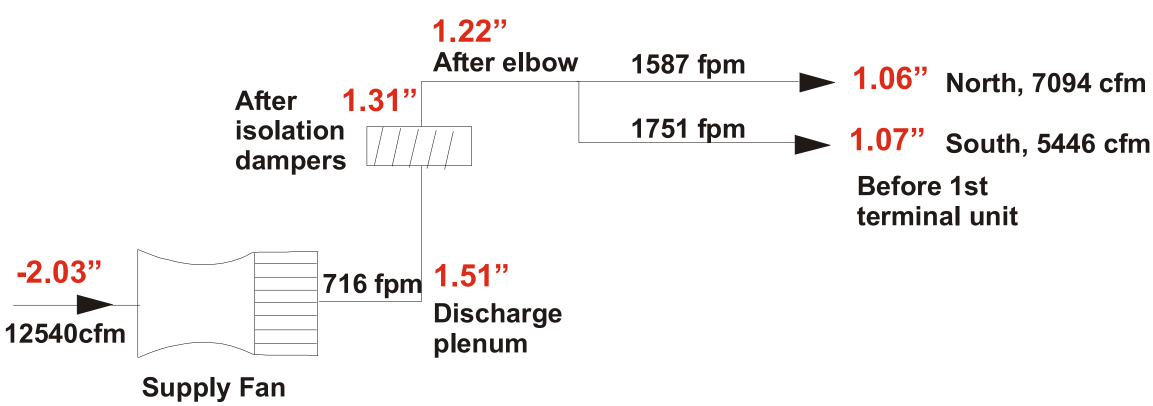

Figure 25. Static Pressure Profile

Figure 26 shows the total pressure profile where the calculated velocity pressure is added to the measured static pressure.

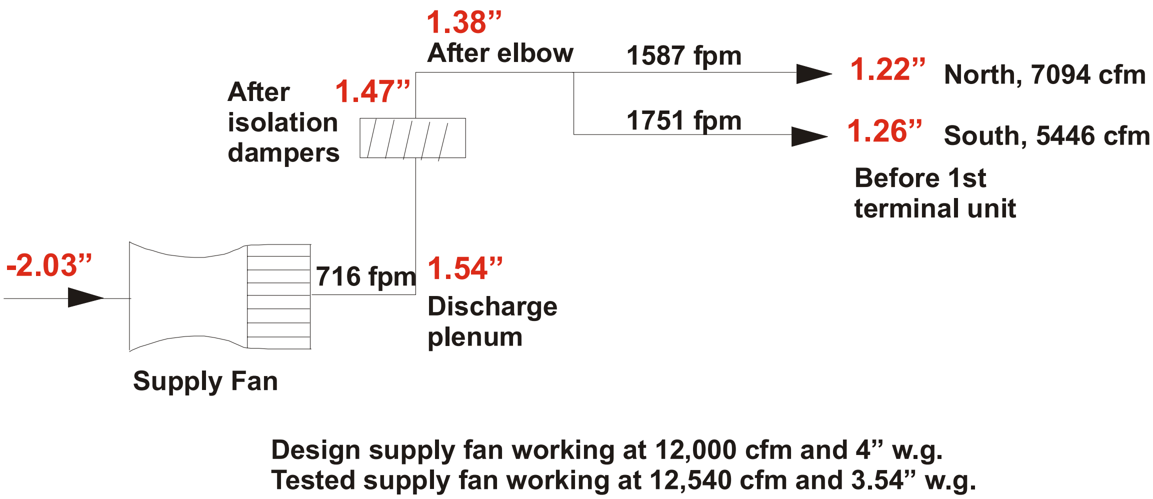

Figure 26. Total Pressure Profile

Table 12. Measured Supply Fan Performance (data covers 8/3/2002 to 1/19/2003)

Case	Date and Time	CFM	Power Watt	VFD %
Maximum Airflow (cfm)	8/11/02 15:00	13,481	47105.3	100
Maximum Power	9/3/02 5:00	12,671	49500.0	100

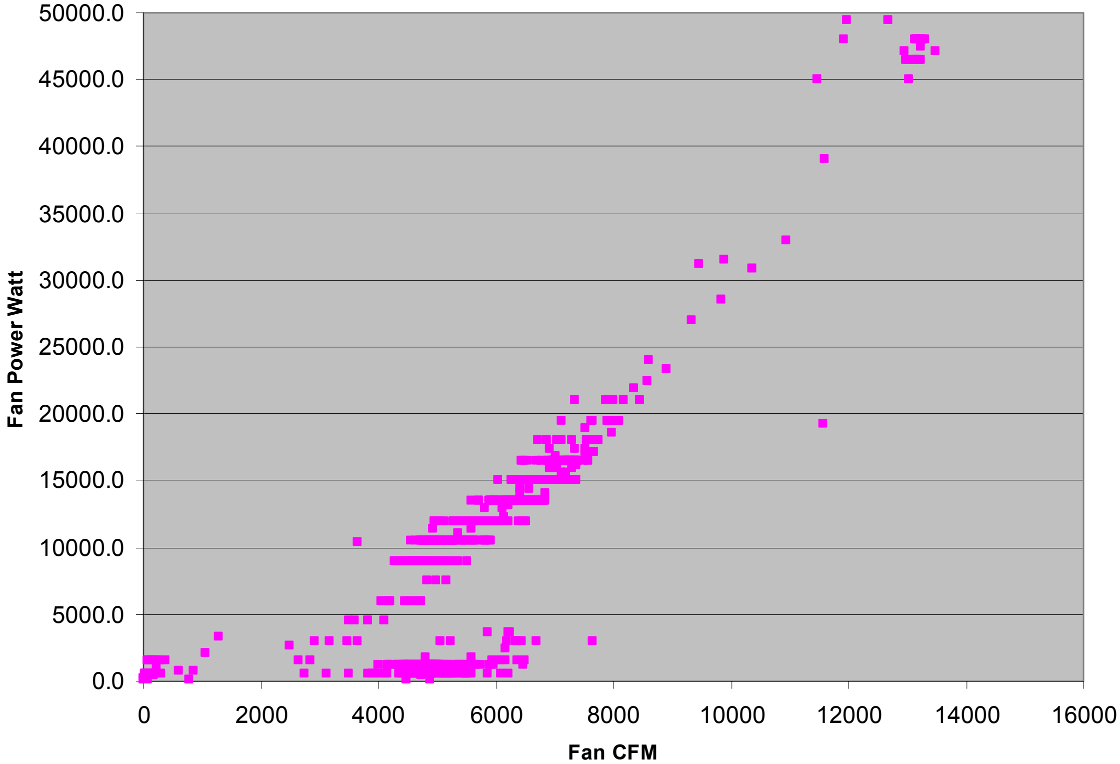

Figure 27. Measured Supply Fan Performance

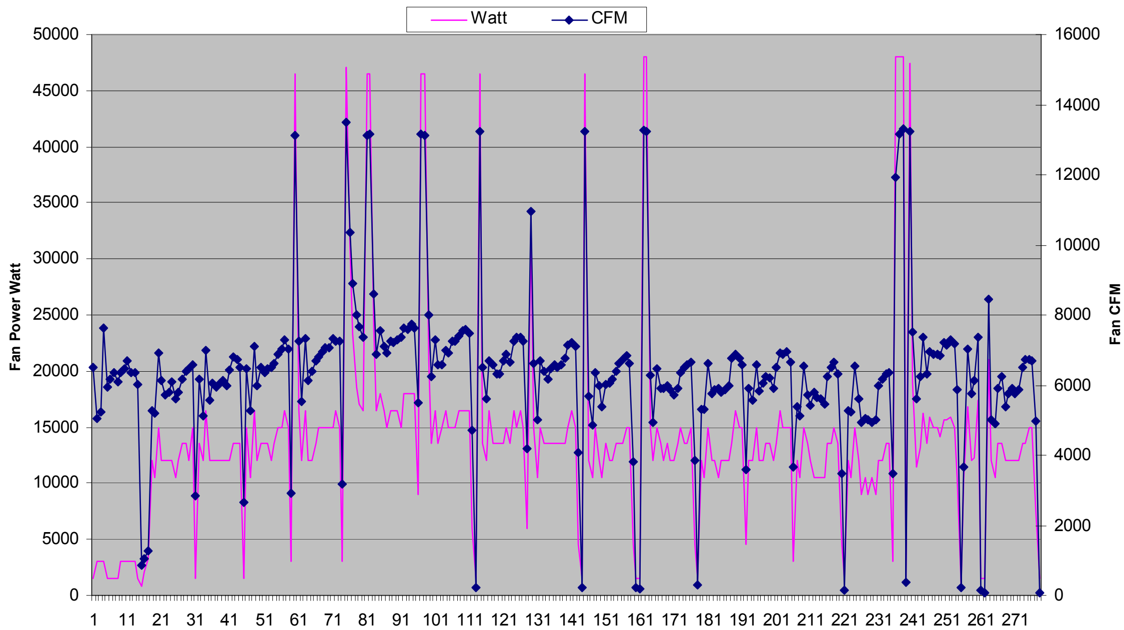

Figure 28. Measured Supply Fan Airflow and Power – August 2002

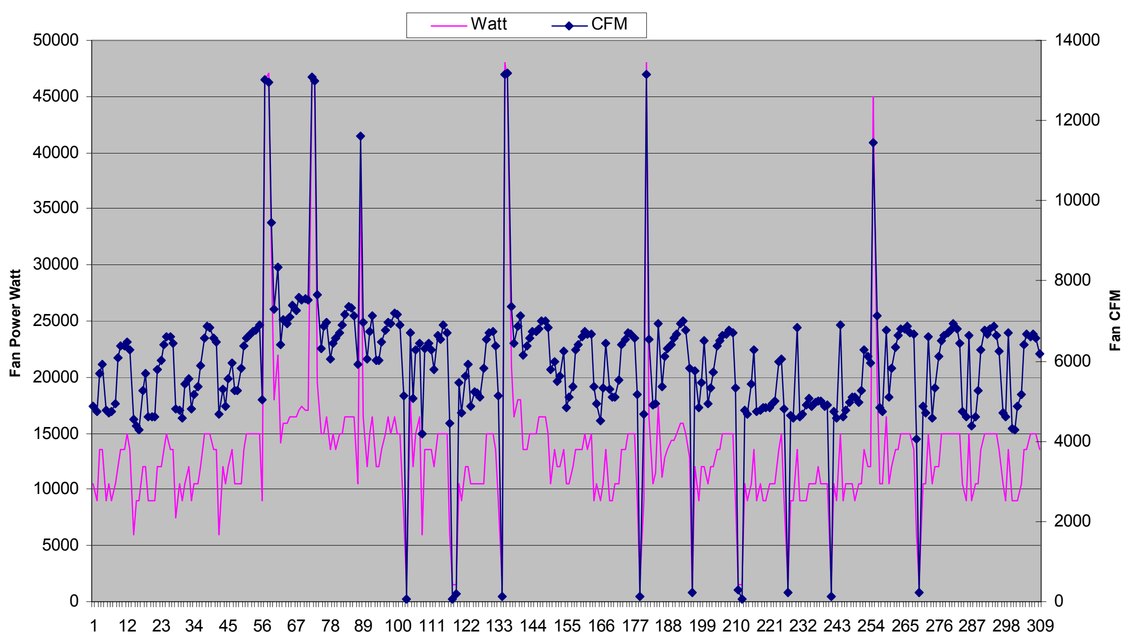

Figure 29. Measured Supply Fan Airflow and Power – October 2002

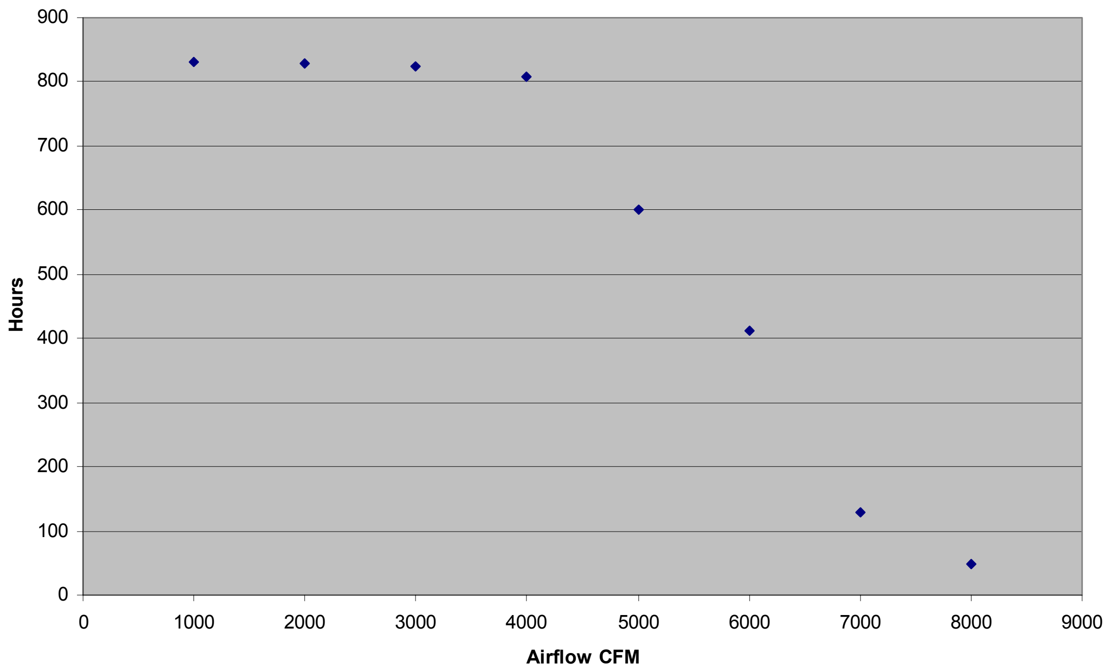

Figure 30. Measured Fan CFM Profile

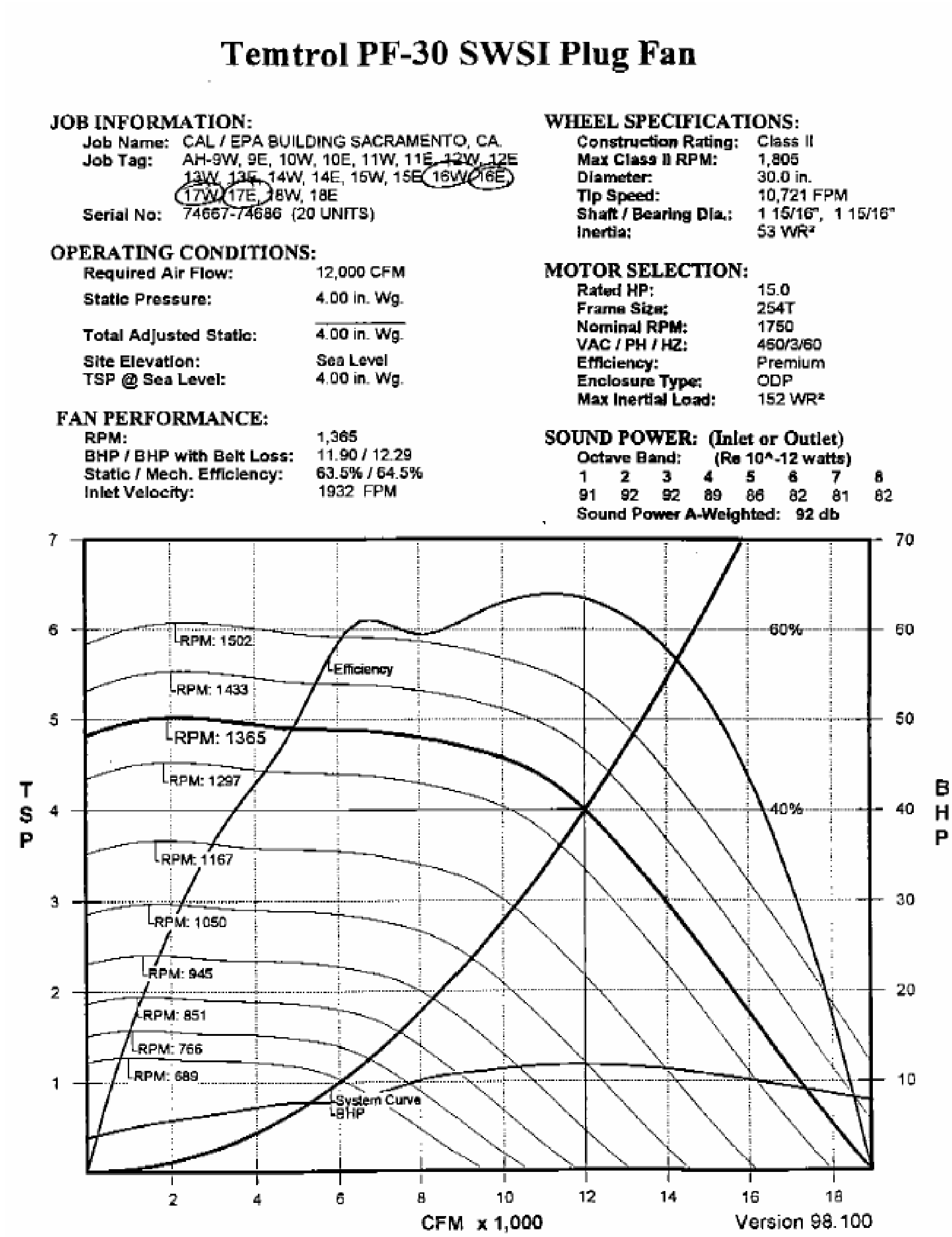

Figure 31. Fan Curve from Manufacturer

The duct layout and the backdrop damper add extra pressure loss to the supply air outlet, this causes fan system effect. But because the duct is oversized, the actual air velocity will be much less than the normal design of 1500 fpm, therefore the pressure drop would not be significant enough to cause problems. Unfortunately, the static pressure sensor on the fan inlet is not working, we cannot get the deltaP across the fan and plot operating points on the manufacturer fan curves to illustrate the fan system effect.

Site 1

[ADD DISCUSSION OF SITE 1 MEASUREMENTS]

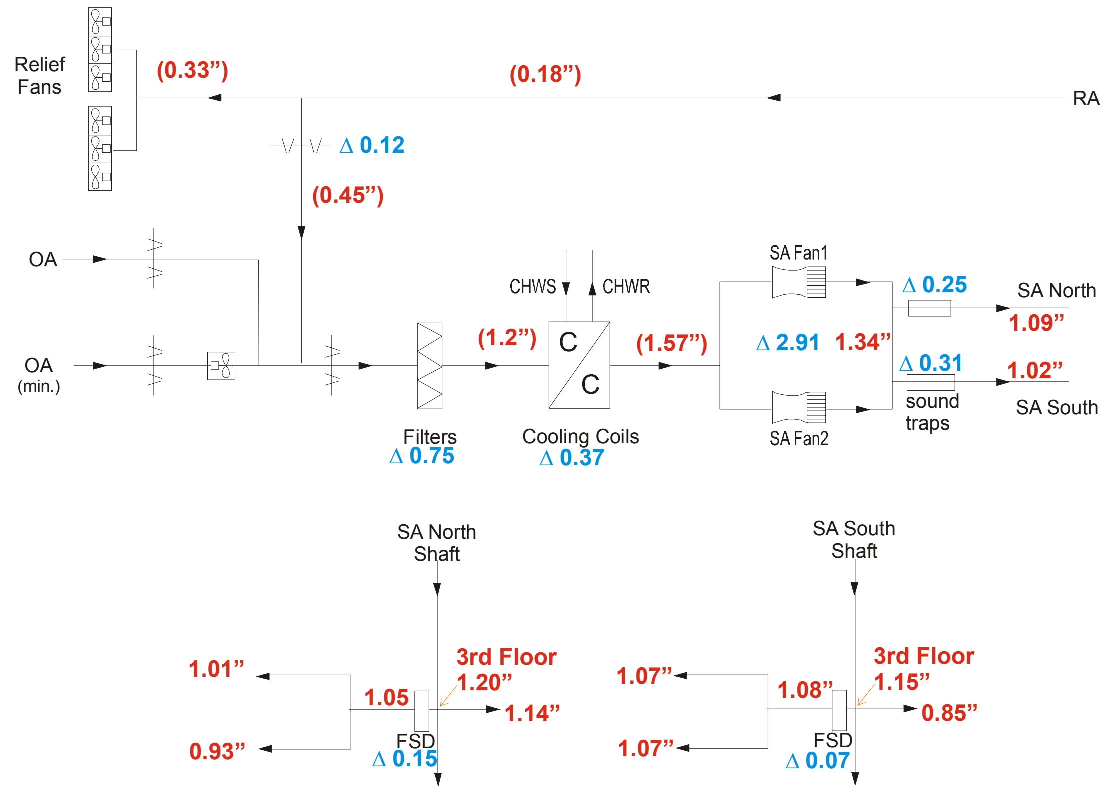

Figure 32. Static Pressure Profile

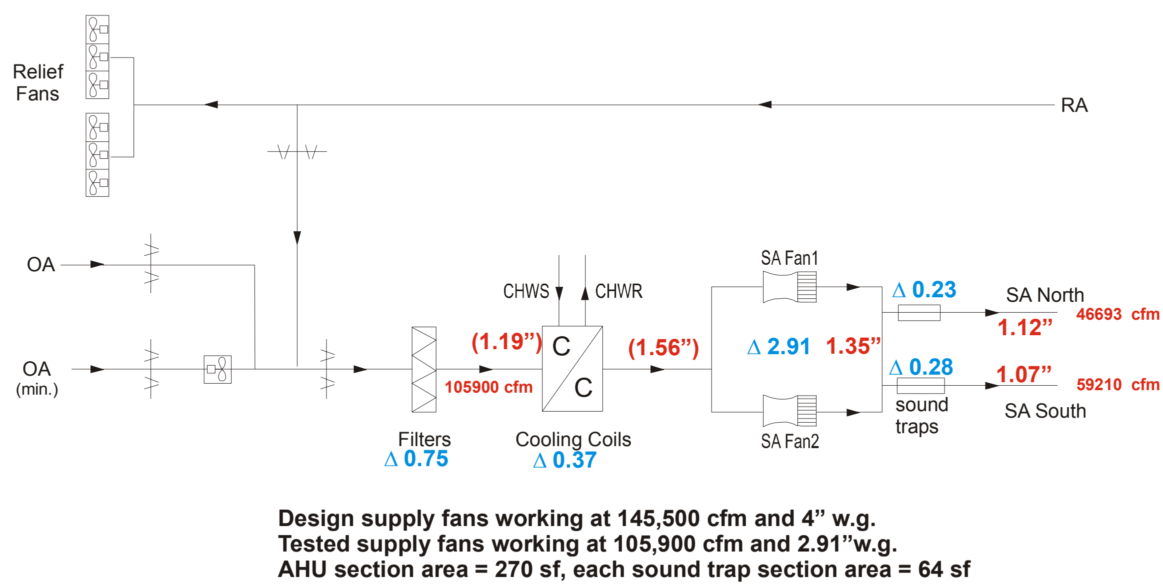

Figure 33. Total Pressure Profile

Recommendations

It is better to plan for system effect in the design. Smooth flow in the fan can help prevent system effect:

Effective duct length

- 2.5 duct diameter 2500 fpm or less
- 1 duct diameter added per 1000 fpm more

Elbows

- Published loss assume even flow
- At inlet, elbows can produce non-uniform flow

Turning vanes

- May increase increase loss downstream
- Can improve flow at inlet

To reduce fan system effect and air pressure loss through duct, it is recommendated to layout air duct first and then the AHU so that sudden turns and changes in air flow can be minimized. Normal design layout AHU first and tries to squeeze air duct into limited space leading to difficulties of smooth duct layout.

REHEAT SOURCE AND CONTROL

Introduction

Hot water reheat systems with gas boilers offer lower energy costs (theoretically) than electric reheat systems, but hot water systems are typically more expensive. In addition, the actual relative energy costs are not well known. The guideline will describe the relative benefits and disadvantages for electric and hot water reheat. It will describe applications where either system may be preferred (e.g. use electric if only a few zones really need reheat or if very few zones are expected to require reheat at the same time).

The current prescriptive Standards mandate the use of hot-water reheat in VAV systems, making the assumption that source energy usage for electric reheat is three times higher than for hot-water reheat. However, this assumption completely neglects the parasitic energy losses associated with a hot-water reheat system; i.e., the pumping energy and the piping thermal losses.

A few VAV boxes serving low-load interior spaces or unoccupied conference rooms may force a central boiler to operate year-round, even when the outdoor temperature is in the 90's. In addition, Title 24 does not require any hot-water temperature reset for the reheat piping distribution network. As a result, the piping network may be operating at the 140-180°F winter design temperature, when a temperature of 100°F or less would suffice for the moderate air tempering required in the summer. The associated piping distribution losses in such a system may easily exceed the annual reheat coil loads.

DOE-2 studies that we and others have conducted suggest that a poorly controlled hot-water reheat system may use as much or more energy as a well-controlled electric reheat system. When piping losses are neglected, DOE-2 may underpredict annual heating energy by a factor of 2 to 3.

The benefits of electric reheat are expected to consist principally of lower first costs, with little or minor increases in energy costs. Maintenance costs will be considerably less due to the simplicity of the components.

The impact of time-dependent valuation has not yet been assessed for this measure. The majority of electric reheat occurs in the winter. The impact of electric reheat during summer peaks will depend in large part on the building and control sequences. These factors will be addressed in the study.

SUPPLY AIR TEMPERATURE CONTROL

Sub-optimal supply air temperature control results in increased overall energy consumption (sum of fan energy, chiller energy, pump energy and reheat energy). Under given conditions, a low set point causes excess cooling and reheat energy while a high set point leads to greater airflow and excess fan energy. The guideline will describe supply air temperature control methods that work best in California and describe when they are appropriate. The recommendations may vary based on several parameters including:

Table 13 Supply Air Temperature Reset Analysis Parameters

Parameter	Type of Impact
Climate (drybulb, solar and also humidity)	Cooler climate = more economizer hours = more benefit from reset. Humid climate = cooler SAT desired for dehumidification = less benefit from reheat
Fan/air handler characteristics (kW vs. flow and SP, coil bypass dampers)	More efficient air distribution system tends to increase benefit of SAT reset
Duct system characteristics (pressure loss vs. flow)	More efficient duct system means more benefit from reset due to less fan penalty from increased airflow.
Chilled water plant characteristics (kW/ton over range of typical operating conditions)	More efficient plant = less benefit from reset because cooling savings are lower
Zone minimum outside air requirements/ other zone minimum airflow constraints (such as VAV box range of controllable airflow)	Higher zone minimum flow requirements lead to greater savings for SAT reset
Reheat source (e.g. electric, hot water, recovered condenser heat, parallel fan-powered box)	More expensive reheat increases benefit to SAT reset
Economizer	Less SAT reset benefit without economizer
Zone load diversity (or likelihood of “rogue” zones)	More zone load diversity = less benefit to SAT reset?
Building envelope design (high load vs. low load)	Large load difference between interior and exterior zones reduces opportunity for reset
Operating schedule (e.g. daytime-only vs. 24 hour), related to total cooling load diversity/ cooling load profile (number of hours at low load)	More operation at night increases savings opportunity for SAT reset because number of low-load hours increases.
Internal heat gain	?

Reset methods to be evaluated include:

1. DOE2 options (by warmest zone, by outside air temp and air-first, temp-first or simultaneous)
2. Methods based on system “mode” (e.g. CHW valve open/closed, economizer, bypass damper status, SP setpoint, OA damper, VAV damper positions, fan operating point, reheat valve status,…) [might require multiple runs and post processing of outputs]

Simulations will imploy a model similar to that used for the evaluation of VAV terminal unit sizing described earlier.

References

Yu-Pei Ke and Stanley A. Mumma "Optimized Supply Air Temperature (SAT) Reset in Variable Air Volume (VAV) Systems". Energy-The International Journal Vol. 22, No.6, pp. 601-614, 1997. see www.sciencedirect.com

> This paper reports combined fan and cooling energy savings of about 6% using an optimal supply air temperature control method relative to fixed supply air temperature. This analysis is based on a Pennsylvania climate.

NIGHT PURGE

Introduction

For buildings, heat gains generated during the day are absorbed by furnishings, walls, floors, and other building surfaces then released over a period of time in proportion to the thermal capacity of the material. Building thermal mass is generally considered to be negative in the case of intermittent air conditioning, since the cooling load tends to increase due to heat storage in building structure.

However for commercial buildings that don't operate during night, the possibility of using night time cool outside air to cool down the thermal mass of the building interior structure (night time purge) during summer and in some climates where there is sufficient variation in diurnal outdoor air temperature, can reduce cooling equipment capacity requirements to meet day time peak loads or save operating costs by utilizing cheap night time electricity.

Successful applications of night time purge demonstrated significant reduction of peak cooling load during day time and energy cost savings if time-of-use rate applies.

This analysis topic will present benefits and disadvantages to night time purge, discuss alternative control strategies, and provide recommendations of effective night time purge applications. Future work is also suggested.

Application

Night time purge has potential benefits of:

- Reducing morning cool-down load
- Reducing day-time peak electrical demand for cooling.
- Reducing cooling energy consumption by using free cooling during night
- Reducing total cooling cost if a time-of-use electricity rate favoring night hours.
- For hot climates, the lower mean interior surface temperature may improve thermal comfort for occupants.

Although night time purge uses free cooling with cool outside air during night, there is fan energy applied, the cost savings may not be guaranteed. Successful application of night time ventilation depends on:

- Weather

  The building should be located in a warm or hot climate zone with sufficient diurnal variation in outdoor air temperature
- Building thermal mass, insulation, infiltration

The building should have adequate thermal mass. The thermal capacity for typical concrete building structure is on the order of 2 – 4 W-h/ºF per square foot of floor area. Solar heat gains should be minimized as much as possible with exterior/interior shading and with high performance glazings. Internal heat gains and air infiltration should also be minimized.

Thermal mass should be combined with adequate insulation of the external envelope of the building. This combination leads to reduced mean internal temperatures and to satisfactory thermal comfort conditions during the summer.

- Control strategies

  Optimal control strategy to determine hourly temperature setpoint of zone should be studied and implemented in building DDC or EMCS systems.

- Utility rate schedule

  The electricity rate should be a time-of-use rate favoring night time hours.

- Occupancy schedule

  The building should be mostly occupied during day and unoccupied during night.

- Part load performance of HVAC equipment

  The HVAC system and equipment like fans and chillers should be able to operate efficiently at part load conditions, for example using the variable speed fans, variable volume chilled water pumping and variable speed chillers.

There are potential issues related to night time purge:

- Moisture problem

  For humid climates, night time purge may bring moisture into the building and cause condensation and indoor air quality problems

- Overcooled problem

  If building structure and zone air are overcooled during early morning occupied hour, occupants may not be comfortable and systems may have to provide extra heating for comfort reasons.

- Outside air quality

  If outside air quality is not good, night time purge may increase the problem of indoor air quality.

- Commissioning of controls

  Night time purge control needs commissioning, temperature sensors need calibration periodically.

Control Strategies

Commercial buildings without night time purge normally sets a comfort range of zone temperature during occupied hours and let zone temperature float for unoccupied hours (Night Setup Control). Some buildings may employ optimal morning startup for HVAC systems.

Braun proposed an optimization control (Precooling Strategy) based on three different temperature setpoints for different periods of a day. The control strategy results in peak cooling load reduction of 25% and energy cost savings with time-of-use electricity rate for a 1.4 million square foot office building located near Chicago.

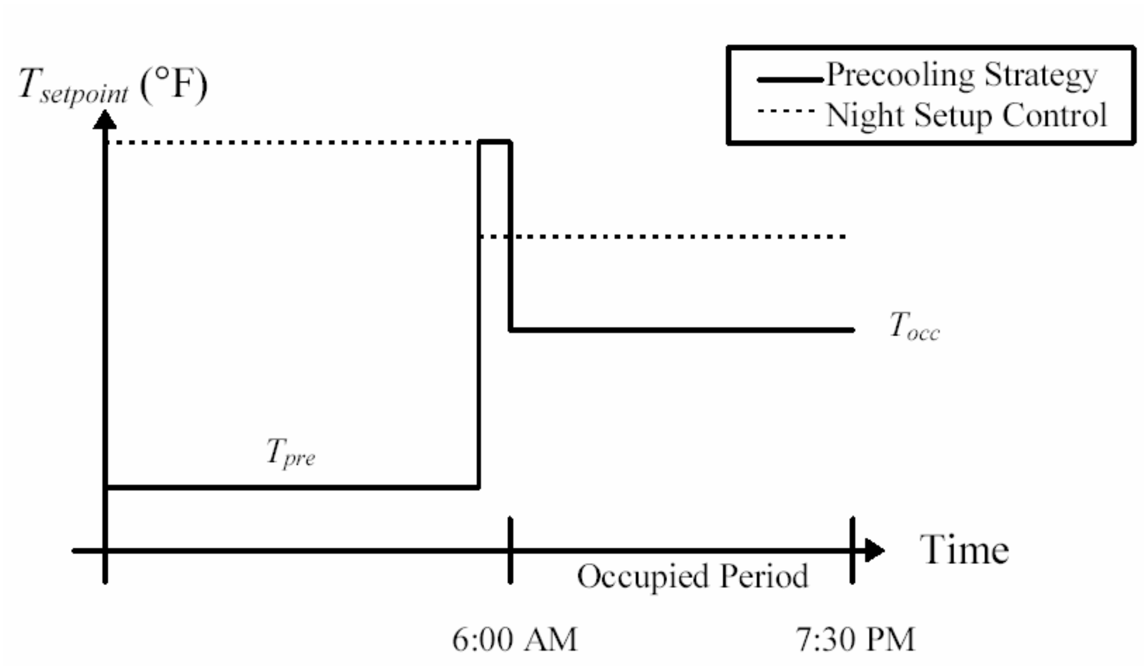

Figure 34. Zone Air Temperature Setpoints (Braun's Control Strategy)

Braun's control strategy relies on the monitoring of hourly indoor and outdoor air temperatures, and cannot deliver an optimal on-off schedule such as turning on and off repeatedly.

Nagai proposed another control algorithm that returns trajectories for space temperature setpoints throughout a specified period (summer months or whole year) that will minimize objective functions such as running cost or peak energy demand. It can be applied to buildings for which the thermal mass allows various choices of temperature setpoints. The algorithm also specifies an optimal on-off schedule for HVAC equipment.

Nagai studied three optimization cases for a constant volume package system serving a 500 m^2 room using Osaka Japan weather data. CASE 0 is the base case that sets zone temperature to 26°C for occupied hours and float for unoccupied hours, CASE-1 minimizes total electricity use, CASE-2 minimizes peak electricity demand, and CASE-3 minimizes total operating cost.

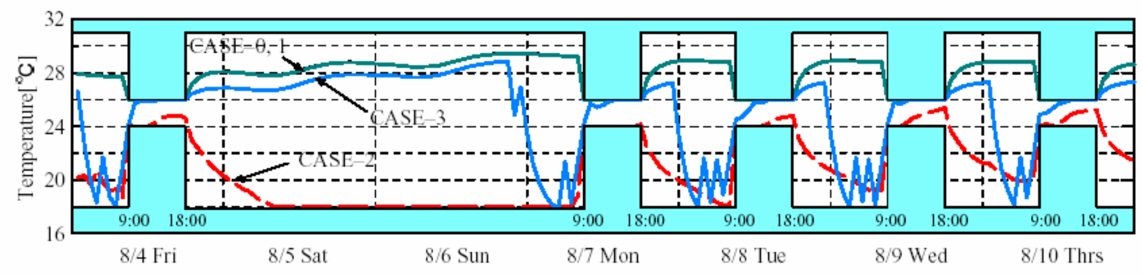

Figure 35. Zone Air Temperature Setpoints (Nagai's Three Control Strategies)

Three optimization controls show different hourly setpoints for zone temperatures.

The complexity of Nagai's control algorithm will hamper its implementation in real time building control systems.

Conclusion

Night time purge is an effective energy conservation technology if applied appropriately to commercial buildings located in certain climate zones with adequate thermal mass and effective control algorithm.

Further quantitative analysis based on building energy simulation will be useful to determine whether this technology applies to commercial buildings in certain area of California. A simple and effective control strategy also needs further research.

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APPENDIX A. SAFTRONIC VSD DATA

SAFTRONICS Inc.
SOLID STATE MOTOR CONTROLS

TN: 089
EFFECTIVE: 27 JAN 94
SUPERSEDES: 30 DEC 91
ORIGINATOR: P. LANDMAN
NO. OF PAGES: 12

G3+ SERIES INVERTER EFFICIENCY (Noisy Version)

PERCENT (%) OF FULL SPEED

MODEL	HP	25%	50%	75%	100%
20P4	1	.101	.467	.731	.847
20P7	1.5	.145	.566	.799	.888
21P5	2	.217	.681	.866	.928
22P2	3	.272	.733	.884	.930
23P7	5	.313	.768	.899	.938
25P5	7.5	.353	.797	.912	.945
27P5	10	.374	.810	.917	.948
2011	20	.384	.815	.919	.949
2015	25	.375	.812	.919	.950
2018	30	.341	.789	.908	.943
2022	40	.349	.794	.911	.945
2030	50	.464	.846	.922	.943
2037	60	.465	.847	.923	.943
2045	75	.513	.878	.945	.963
2055	100	.517	.878	.945	.962
2075	125	.512	.876	.944	.962
40P4	1	.109	.483	.740	.849
40P7	1.5	.170	.606	.816	.892
41P5	2	.269	.731	.884	.932
42P2	3	.309	.768	.903	.943
43P7	5	.354	.799	.914	.948
45P5	7.5	.373	.811	.919	.950
47P5	10	.412	.832	.927	.954
4011	20	.469	.863	.943	.965
4015	25	.496	.875	.948	.967
4018	30	.495	.875	.948	.967
4022	40	.503	.879	.949	.968
4030	50	.462	.855	.935	.957
4037	60	.505	.873	.943	.961
4045	75	.472	.863	.941	.963
4055	100	.548	.891	.950	.966
4075	150	.575	.899	.953	.968
4110	200	.611	.912	.959	.971
4160	250	.612	.913	.961	.973
4185	300	.611	.911	.958	.970
4220	400	.611	.911	.958	.970
4300	500	.608	.909	.956	.969

NOTES: 1. Above values based on Variable Torque Load with carrier frequency set on 2.5KHz for models 20P4-2022 and 40P4-4045 and 2.1KHz for models 2030-2075 and 4055-4300.

PAGE 2
TN 089

G3+ SERIES INVERTER EFFICIENCY (Low Noise Version)

PERCENT (%) OF FULL SPEED

MODEL	HP	25%	50%	75%	100%
20P4	1	.094	.442	.705	.825
20P7	1.5	.127	.526	.771	.870
21P5	2	.197	.651	.847	.915
22P2	3	.253	.710	.867	.917
23P7	5	.296	.747	.883	.924
25P5	7.5	.338	.780	.898	.932
27P5	10	.353	.790	.903	.935
2011	20	.362	.796	.904	.935
2015	25	.356	.794	.906	.938
2018	30	.324	.770	.893	.930
2022	40	.331	.775	.896	.931
40P4	1	.101	.462	.720	.833
40P7	1.5	.153	.571	.789	.870
41P5	2	.248	.706	.867	.917
42P2	3	.297	.753	.891	.932
43P7	5	.340	.783	.901	.936
45P5	7.5	.352	.792	.906	.939
47P5	10	.382	.810	.913	.942
4011	20	.450	.850	.933	.956
4015	25	.473	.861	.938	.959
4018	30	.474	.861	.938	.959
4022	40	.479	.864	.939	.960
4030	50	.433	.835	.921	.944
4037	60	.484	.833	.922	.946
4L45	75	.444	.837	.919	.942

NOTES: 1. Above values based on Variable Torque Load and Carrier Frequency set on maximum allowable per rating (15KHz, except: 4037 = 10KHz, 4L45 = 10KHz).

APPENDIX B. FAN SYSTEM ANALYSIS CODE

Main Routines

Sub RunScenarios

```
Sub RunScenarios()
' Subroutine to run each scenario in the Scenarios table.
' A scenario consists of a single fan system and a single load profile.
' For each scenario it runs through the entire load profile.
' Calculates power consumption of each subcomponent (fan,motor,VSD,belt)
' for each pt of data in the load profile.
' This subroutine also stages the fans if there are two in parrallel based
' either on optimal staging or based on the staging reported in the load profile.

Dim dbActive As Database
Dim rstFanData As Recordset, rstFanDataTemp As Recordset, rstFanHeader As Recordset
Dim rstScenarios As Recordset 'Scenarios table
Dim rstLoadProfiles As Recordset 'this table has the LPID and the LP filename
Dim rstLoadProfile As Recordset 'load profile table
Dim rstResults As Recordset 'results table
Dim rstFanSystems As Recordset 'all fan systems are in this table
Dim iScenario As Integer 'scenario counter
Dim rstMotorHeader As Recordset, rstVSDHeader As Recordset, rstBeltHeader As Recordset
Dim dTemp As Double
'fan system variables
Dim iSID As Integer, iFID As Integer, iMID As Integer
Dim iVID As Integer, iBID As Integer, dDesignRPM As Double, dMinSpeed As Double
Dim j As Integer, dExtraDP As Double, dDesignCFM As Double, dExtraSCC As Double
'scenario variables
Dim iFSID As Integer, iLPID As Integer
Dim bMirrorStaging As Boolean 'if true then use the staging in the load profile else
stage optimally
Dim i As Integer, iScenarioNumFans As Integer 'this is 2 for parallel fans or 1 for
single fan air handler.
Dim dDateRun As Date 'This will tell if the scenario has already been run.
                    'The idea is to manually delete DateRun from Scenarios table to rerun
the scenario
'load profiles variables
Dim sLPFilename As String
Dim dDateTime As Date
Dim dCFM As Double, dDP As Double, dSCC As Double, dGamma As Double
Dim iLPNumFans As Integer 'this is the number of fans actually operating based on
monitored data
                        'It is only useful if trying to model basecase staging.
Dim dDPlowerbound As Double, dDPupperbound As Double
'fan variables
Dim oGFan As GammaFan
Dim dSCCMin As Double, dSCCMax As Double
Dim dPLow As Double, dPHigh As Double, dGammaSurge As Double
Dim sSQL  As String
Dim dDia As Double, dPhi As Double, dPctSpeed(2) As Double
Dim bTest As Boolean

'motor variables
Dim oMotor As Motor
'VSD variables
Dim oVSD As VSD
'Belt Variables
Dim oBelt As Belt
'Results Variables
Dim rstResultsDataBlank As Recordset
Dim sResultsFileName As String
Dim dPt3 As Double, dPt2 As Double
Dim iNumFansNow As Integer 'this is the number of fans running for a particular record
'need 2 copies of these results variables for single and parralel operation
Dim dFanEff(2) As Double, dFanBHP(2) As Double, dFanRPM(2) As Double
Dim dKW(2) As Double, dFanKW(2) As Double
Dim dMotorEff(2) As Double, dMotorKW(2) As Double
Dim dVSDEff(2) As Double, dVSDKW(2) As Double
Dim dBeltEff(2) As Double, dBeltKW(2) As Double
Dim bTooHighGammaPower(2) As Boolean, bTooLowGammaPower(2) As Boolean
Dim bTooHighGammaRPM(2) As Boolean, bTooLowGammaRPM(2) As Boolean, bSurge(2) As Boolean
Dim bTooHighBHP(2) As Boolean
```

```
'set recordsets for scenarios and fan systems and loadprofiles
Set dbActive = CurrentDb()
Set rstScenarios = dbActive.OpenRecordset("Scenarios", dbOpenTable)
Set rstFanSystems = dbActive.OpenRecordset("FanSystems", dbOpenTable)
Set rstLoadProfiles = dbActive.OpenRecordset("LoadProfiles", dbOpenTable)
' Set recordsets for blank ResultsData file
Set rstResultsDataBlank = dbActive.OpenRecordset("ResultsDataBlank", dbOpenTable)
' Set recordsets for fan header and data
Set rstFanHeader = dbActive.OpenRecordset("FanHeader", dbOpenTable)
Set rstFanData = dbActive.OpenRecordset("FanData", dbOpenTable)
' Create fan, belt, motor and VSD objects
Set oGFan = New GammaFan
Set oBelt = New Belt
Set oMotor = New Motor
Set oVSD = New VSD
'set recordsets for rest of the equipment
Set rstMotorHeader = dbActive.OpenRecordset("MotorHeader", dbOpenTable)
Set rstVSDHeader = dbActive.OpenRecordset("VSDHeader", dbOpenTable)
Set rstBeltHeader = dbActive.OpenRecordset("BeltHeader", dbOpenTable)

'Loop through each Scenario
rstScenarios.MoveFirst
Do While Not rstScenarios.EOF
If IsNull(rstScenarios.Fields("DateRun").Value) Then 'only run this scenario if DateRun
is blank
    'Retrieve data for this scenario from Scenarios table
    iSID = rstScenarios.Fields("SID").Value
    iFSID = rstScenarios.Fields("FSID").Value
    iLPID = rstScenarios.Fields("LPID").Value
    iScenarioNumFans = rstScenarios.Fields("NumFans").Value
    bMirrorStaging = rstScenarios.Fields("MirrorStaging").Value

    'retrieve data for this fan system from FanSystems
    rstFanSystems.Index = "FSID"
    rstFanSystems.Seek "=", iFSID
    iFID = rstFanSystems.Fields("FID").Value
    iMID = rstFanSystems.Fields("MID").Value
    iVID = rstFanSystems.Fields("VID").Value
    iBID = rstFanSystems.Fields("BID").Value
    dDesignRPM = rstFanSystems.Fields("DesignRPM").Value
    dMinSpeed = rstFanSystems.Fields("MinSpeed").Value
    dExtraDP = rstFanSystems.Fields("ExtraDP").Value
    dDesignCFM = rstFanSystems.Fields("DesignCFM").Value
    ' calculate the system curve coefficient for the extra fan-specific DP
    dExtraSCC = dExtraDP / dDesignCFM ^ 2

    'retrieve LP filename from LoadProfiles
    rstLoadProfiles.Index = "LPID"
    rstLoadProfiles.Seek "=", iLPID
    sLPFilename = rstLoadProfiles.Fields("FileName").Value
    'set load profile for this scenario
    Set rstLoadProfile = dbActive.OpenRecordset(sLPFilename, dbOpenTable)

    'copy ResultsDataBlank and save with appropriate name
    sResultsFileName = "ResultsDataSID" & iSID
    Call DeleteIfExisting(sResultsFileName)
    Call CopyTable(rstResultsDataBlank, sResultsFileName)
    Set rstResults = dbActive.OpenRecordset(sResultsFileName, dbOpenTable)

    'Retrieve from equip tables: high and low boundaries for BHP and RPM, criticalgamma
    ' and all coefficients for each component

    'Get fan
    rstFanHeader.Index = "Fan ID"
    rstFanHeader.Seek "=", iFID
    'Select data for this fan
    sSQL = "SELECT FDID, Gamma, SCC"
    sSQL = sSQL & " FROM " & rstFanData.Name & " WHERE FanID="
    sSQL = sSQL & iFID
    Set rstFanDataTemp = dbActive.OpenRecordset(sSQL)
    'Substantiate oGFan with the model
    Call oGFan.xsGetFan(rstFanHeader, rstFanDataTemp)
    dSCCMin = oGFan.xfSCCMin(rstFanDataTemp)
    dSCCMax = oGFan.xfSCCMax(rstFanDataTemp)
    dPLow = oGFan.xfGammaPLow(rstFanDataTemp)
    dPHigh = oGFan.xfGammaPHigh(rstFanDataTemp)
    dGammaSurge = oGFan.GammaSurge
    dDia = oGFan.DIA
```

```
    ' You now have a populated fan with curves, GammaSurge and Min/Max SCCs

    'retrieve motor data
    rstMotorHeader.Index = "MID"
    rstMotorHeader.Seek "=", iMID
    Call oMotor.xsGetMotor(rstMotorHeader)
    'retrieve VSD data
    rstVSDHeader.Index = "VID"
    rstVSDHeader.Seek "=", iVID
    Call oVSD.xsGetVSD(rstVSDHeader)
    'retrieve belt data
    rstBeltHeader.Index = "BID"
    rstBeltHeader.Seek "=", iBID
    Call oBelt.xsGetBelt(rstBeltHeader)
    'Loop through each data pt in load profile
    rstLoadProfile.MoveFirst
    Do While Not rstLoadProfile.EOF

        'load DateTime, CFM, DP from LoadProfile table
        dDateTime = rstLoadProfile("DateTime").Value
        dCFM = rstLoadProfile("CFM").Value
        iLPNumFans = rstLoadProfile("NumFans").Value
        ' Do all the calcs single fan operation and dual if appropriate. Later we will
compare single and dual for optimal staging
        For i = 1 To iScenarioNumFans
            dDP = rstLoadProfile("DP").Value 'DP is loaded here because it could get
reset during single fan if below MinSpeed
            dCFM = dCFM / i 'CFM is now the CFM seen be each fan if there are two fans
            dDP = dDP + dExtraSCC * dCFM ^ 2 'dDP is increased by the extra fan-specific
static if specified in the fan system
            dSCC = oGFan.xfSCC(dCFM, dDP)
            dPctSpeed(i) = 1#  'reset PctSpeed to avoid hitting the MinSpeed unnecesarily
            'calculate Gamma for this pt and determine if in surge
            dGamma = oGFan.xfGamma(dCFM, dDP)
            If dGamma < dGammaSurge Then
                bSurge(i) = True
                Else
                bSurge(i) = False
            End If

            'assume pt is within tuning range until proven otherwise
            bTooHighBHP(i) = False
            bTooHighGammaPower(i) = False
            bTooLowGammaPower(i) = False
            'calculate fan efficiency and bhp if within tuning range
            If dSCC > dSCCMin Then
                bTooLowGammaPower(i) = True
            End If
            If dSCC < dSCCMax Then
                    bTooHighGammaPower(i) = True
            End If
            If dSCC <= dSCCMin And dSCC >= dSCCMax Then
                ' Use this for fan efficiency
                dFanEff(i) = oGFan.xfEff(dCFM, dDP)
                dFanBHP(i) = dCFM * dDP / (6350 * dFanEff(i))
                'set boolean to false if BHP is greater than MHP
                If dFanBHP(i) > oMotor.MHP Then
                    bTooHighBHP(i) = True
                End If
            End If
            'first check if the RPM tuning data covered this pt
            bTooLowGammaRPM(i) = False
            bTooHighGammaRPM(i) = False
            If dGamma < dPLow Then
                bTooLowGammaRPM(i) = True
            End If
            If dGamma > dPHigh Then
                bTooHighGammaRPM(i) = True
            End If
            If dGamma >= dPLow And dGamma <= dPHigh Then 'if within tuning range then
calc, Phi,RPM,pctSpeed
                 dFanRPM(i) = oGFan.xfRPM(oGFan.xfPhi(dFanEff(i), dCFM, dDP), dCFM)
                dPctSpeed(i) = dFanRPM(i) / dDesignRPM
            End If
'NEW STUFF FOR MIN SPEED
            If dPctSpeed(i) < dMinSpeed Then 'We need to ride up the RPM curve to get the
new DP
                dDPlowerbound = dDP
                'Map the CFM onto the MinGammaRPM System Curve to get DPupper-bound.
DPub = SCCMinGammaRPM *CFM^2
```

```
                dDPupperbound = (2.718 ^ (-1 * dPLow)) * dCFM ^ 2
                ' Solve for fan eff,RPM,pctSpeed at CFM, DPupper-bound.
                dFanEff(i) = oGFan.xfEff(dCFM, dDPupperbound)
                dFanRPM(i) = oGFan.xfRPM(oGFan.xfPhi(dFanEff(i), dCFM, dDPupperbound),
dCFM)
                dPctSpeed(i) = dFanRPM(i) / dDesignRPM

                If dPctSpeed(i) < dMinSpeed Then 'the desired pt is outside the tuning
range
                    bTooLowGammaRPM(i) = True
                Else 'find the correct DP that matches this CFM and this MinSpeed
                    For j = 1 To 15 'this is a classic search routine to get zero in on
the desired result
                        dDP = (dDPupperbound + dDPlowerbound) / 2
                        'Solve for fan eff, RPM, pctSpeed
                        dFanEff(i) = oGFan.xfEff(dCFM, dDP)
                        dFanRPM(i) = oGFan.xfRPM(oGFan.xfPhi(dFanEff(i), dCFM, dDP),
dCFM)
                        dPctSpeed(i) = dFanRPM(i) / dDesignRPM
                        If dPctSpeed(i) > dMinSpeed Then 'rebound the search depending on
over or undershoot
                             dDPupperbound = dDP
                        Else
                            dDPlowerbound = dDP
                        End If
                    Next 'end of loop
                End If 'tuning range on RPM curve
            End If 'below minSpeed
            'Now we have the fan eff, RPM, pctSpeed, and DP for the desired point
         'Now we need to re-calc the fan bhp, and calc the motor eff, vsd eff, etc. but
         'don't bother if pt is out of range
         bTest = Not bTooHighGammaPower(i) And Not bTooLowGammaPower(i) _
            And Not bTooHighGammaRPM(i) And Not bTooLowGammaRPM(i)
'            And Not bTooHighBHP(i)
         If bTest Then
         dFanBHP(i) = dCFM * dDP / (6350 * dFanEff(i))
             'calculate motor eff
             dMotorEff(i) = oMotor.xfEff(dFanBHP(i))
            'calc VSD eff from coeffs
            dVSDEff(i) = oVSD.xfEff(oMotor.xfPctLoad(dFanBHP(i)))
            'calc belt eff
            dBeltEff(i) = oBelt.xfEff(dFanBHP(i))
            'calc power of fan, motor, belt and VSD
            ' Calc power for fan
            dFanKW(i) = 0.7457 * dFanBHP(i)
            'Calc Total power including belt, motor and VSD
            dKW(i) = dFanKW(i) / (dBeltEff(i) * dMotorEff(i) * dVSDEff(i))
            'Calc VSD power
            dPt3 = dKW(i) * dVSDEff(i) ' This is the power at the motor
            dVSDKW(i) = dKW(i) - dPt3 'KW consumed in VSD
            'Calculate the Motor power
            dPt2 = dPt3 * dMotorEff(i) 'This is the power at the
            dMotorKW(i) = dPt3 - dPt2 'Motor power
            ' Calculate the belt power
            dBeltKW(i) = dPt2 - dFanKW(i)
       End If 'for out of tuning range

       'double the powers for 2 fans in parallel
       dFanKW(i) = dFanKW(i) * i
       dMotorKW(i) = dMotorKW(i) * i
       dVSDKW(i) = dVSDKW(i) * i
       dBeltKW(i) = dBeltKW(i) * i
       dKW(i) = dKW(i) * i

        Next 'end loop for single or parallel fan calcs

        'calculate the staging based on Flag or optimal
        iNumFansNow = 1
        'Optimal First
        If iScenarioNumFans = 2 Then
            If dKW(2) < dKW(1) Then 'another type of semi-optimal staging would be to
compare pctSpeed(1) to a pre-determined staging speed
                iNumFansNow = 2
            Else
                iNumFansNow = 1
            End If
            bTest = Not bTooHighGammaPower(1) And Not bTooLowGammaPower(1) _
                    And Not bTooHighGammaRPM(1) And Not bTooLowGammaRPM(1) _
                    And Not bTooHighBHP(1)
            If Not bTest Then ' 1 is bad
```

```
                iNumFansNow = 2
            End If
            bTest = Not bTooHighGammaPower(2) And Not bTooLowGammaPower(2) _
                    And Not bTooHighGammaRPM(2) And Not bTooLowGammaRPM(2) _
                    And Not bTooHighBHP(2)
            If Not bTest Then ' 2 is bad
                iNumFansNow = 1
            End If
            ' Note if both are illegal the result isn't recorded at all
        End If
        'now check for flag
        If iScenarioNumFans = 2 Then
            If bMirrorStaging Then
                 iNumFansNow = iLPNumFans
            End If
        End If

    'record results
    bTest = Not bTooHighGammaPower(iNumFansNow) And Not bTooLowGammaPower(iNumFansNow) _
            And Not bTooHighGammaRPM(iNumFansNow) And Not bTooLowGammaRPM(iNumFansNow) _
            And Not bTooHighBHP(iNumFansNow)
    rstResults.AddNew
    rstResults.Fields("DateTime").Value = dDateTime
    rstResults.Fields("SID").Value = iSID
    rstResults.Fields("TooHighGammaPower").Value = bTooHighGammaPower(iNumFansNow)
    rstResults.Fields("TooLowGammaPower").Value = bTooLowGammaPower(iNumFansNow)
    rstResults.Fields("TooHighGammaRPM").Value = bTooHighGammaRPM(iNumFansNow)
    rstResults.Fields("TooLowGammaRPM").Value = bTooLowGammaRPM(iNumFansNow)
    rstResults.Fields("Surge").Value = bSurge(iNumFansNow)
    rstResults.Fields("TooHighBHP").Value = bTooHighBHP(iNumFansNow)
    If bTest Then

    'only record energy results if within tuning range and MHP is not exceeded.
        rstResults.Fields("FanBHP").Value = dFanBHP(iNumFansNow)
        rstResults.Fields("FanEff").Value = dFanEff(iNumFansNow)
        rstResults.Fields("FanRPM").Value = dFanRPM(iNumFansNow)
        rstResults.Fields("FanKW").Value = dFanKW(iNumFansNow)
        rstResults.Fields("MotorEff").Value = dMotorEff(iNumFansNow)
        rstResults.Fields("MotorKW").Value = dMotorKW(iNumFansNow)
        rstResults.Fields("VSDEff").Value = dVSDEff(iNumFansNow)
        rstResults.Fields("VSDKW").Value = dVSDKW(iNumFansNow)
        rstResults.Fields("BeltEFF").Value = dBeltEff(iNumFansNow)
        rstResults.Fields("BeltKW").Value = dBeltKW(iNumFansNow)
        rstResults.Fields("KW").Value = dKW(iNumFansNow)
        rstResults.Fields("PctSpeed").Value = dPctSpeed(iNumFansNow)

        rstResults.Fields("CFMperFan").Value = rstLoadProfile("CFM").Value / iNumFansNow
        rstResults.Fields("DPactual").Value = dDP
        rstResults.Fields("NumFans").Value = iNumFansNow


    End If
        rstResults.Update

    'end data pt loop, go to next data pt.
    rstLoadProfile.MoveNext
    Loop

'write the current datetime to the scenarios record to indicate that this scenario has
been run
rstScenarios.Edit
rstScenarios.Fields("DateRun") = Now
rstScenarios.Update

End If 'this is for whether or not the scenario has already been run
'end scenario ID loop, go to next scenario
rstScenarios.MoveNext
Loop

'calculate summary statistics including TOU electric rates

End Sub
```

Sub RunScenarioGroups

```
Sub RunScenarioGroups()
' for each scenario group which has not already been run
' determines the common subset of LP records for which all scenarios in that group are
valid
' calculates ResultsTOU stats based on the common subset
' Note: do not delete any ResultsData table until this procedure has been run
```

```
Dim dbActive  As Database
Dim rstTemp As Recordset, rstResultsTOU As Recordset, rstResultsAnnual As Recordset
Dim rstScenarioGroup As Recordset
Dim iSID As Integer, iSGID As Integer
Dim bFirst As Boolean
Dim sTempTableName As String, sSQL As String
Dim rstScenario As Recordset
Dim rstJoinScenariosToGroups As Recordset
Dim sCurrentResultName As String
Dim qdfTemp As QueryDef
Set dbActive = CurrentDb()
Set rstScenarioGroup = dbActive.OpenRecordset("ScenarioGroups")
Set rstResultsTOU = dbActive.OpenRecordset("ResultsTOU")
Set rstResultsAnnual = dbActive.OpenRecordset("ResultsAnnual")
Set rstJoinScenariosToGroups = dbActive.OpenRecordset("JoinScenariosToGroups")
Set rstScenario = dbActive.OpenRecordset("Scenarios")
Dim dDateRun As Date 'This will tell if the scenario group has already been run.
                    'The idea is to manually delete DateRun from ScenarioGroups table to
rerun the scenario

'clear the results table first
Call ClearRst(rstResultsTOU) 'in future we may want to only delete the records in this
scenario group
Call ClearRst(rstResultsAnnual) 'in future we may want to only delete the records in this
scenario group

rstScenarioGroup.MoveFirst
Do While Not rstScenarioGroup.EOF
If IsNull(rstScenarioGroup.Fields("DateRun").Value) Then 'only run this scenario group if
DateRun is blank
    iSGID = rstScenarioGroup.Fields("SGID").Value
    ' need to filter scenarios for the SGID using a select query
    'start with the whole set of scenarios
    Set rstScenario = dbActive.OpenRecordset("Scenarios")
    'then filter for only ones with this SGID
    sSQL = "SELECT " & rstScenario.Name & ".*"
    sSQL = sSQL & " FROM " & rstJoinScenariosToGroups.Name
    sSQL = sSQL & " INNER JOIN " & rstScenario.Name & " ON " &
rstJoinScenariosToGroups.Name & ".SID = " & rstScenario.Name & ".SID "
    sSQL = sSQL & " WHERE (((" & rstJoinScenariosToGroups.Name & ".SGID)=" & iSGID &
"));"

    Set rstScenario = dbActive.OpenRecordset(sSQL)
    rstScenario.MoveFirst
    bFirst = True
    sTempTableName = "tmpDateTimes"
    Do While Not rstScenario.EOF
        iSID = rstScenario.Fields("SID").Value
        sCurrentResultName = "ResultsDataSID" & iSID
            If bFirst Then
                bFirst = False
                Call DeleteIfExisting(sTempTableName)
                ' Create table of datetimes
                sSQL = "SELECT DateTime, ""ABCDEFG"" AS TOUSeason, ""ABCDEFGHIJK"" AS
TOUBin, ""HI MARK"" AS Month INTO " & sTempTableName & " FROM " & sCurrentResultName & "
WHERE ((TooHighGammaPower=False) AND (TooLowGammaPower=False) AND (TooHighGammaRPM=False)
AND (TooLowGammaRPM=False) AND (TooHighBHP=False));"
                Set qdfTemp = dbActive.CreateQueryDef()
                qdfTemp.Name = "" 'This is a temp query (not stored)
                qdfTemp.SQL = sSQL
                qdfTemp.Execute
                ' Update TOU Information
                sSQL = "UPDATE " & sTempTableName & " SET TOUSeason =
IIf(Month(DateTime)>4 And Month(DateTime)<11,""Summer"",""Winter""), Month =
Month([DateTime]), TOUBin = IIf(Weekday([DateTime])>1 And
Weekday([DateTime])<7,IIf(Hour([DateTime])<9,""OffPeak"",IIf(Hour([datetime])<12,""Partia
lPeak"",IIf(Hour([datetime])<18,""Peak"",IIf(Hour([datetime])<22,""PartialPeak"",""OffPea
k"")))),""OffPeak"");"
                qdfTemp.SQL = sSQL
                qdfTemp.Execute
            Else
                'Delete records if flags are bad
                sSQL = "DELETE DateTime FROM " & sTempTableName & " WHERE DateTime In
(SELECT DateTime FROM " & sCurrentResultName & "  WHERE ((TooHighGammaPower=True) OR
(TooLowGammaPower=True) OR (TooHighGammaRPM=True) OR (TooLowGammaRPM=True) OR
(TooHighBHP=True));); "
                Set qdfTemp = dbActive.CreateQueryDef()
                qdfTemp.Name = "" 'This is a temp query (not stored)
                qdfTemp.SQL = sSQL
                qdfTemp.Execute
```

```
            End If
        rstScenario.MoveNext
    '    Debug.Print iSID
    Loop
    ' Calculate the results for each scenario
    rstScenario.MoveFirst
    bFirst = True
    sTempTableName = "tmpDateTimes"
    Do While Not rstScenario.EOF
        iSID = rstScenario.Fields("SID").Value
        sCurrentResultName = "ResultsDataSID" & iSID
    ' Calculate KWH by TOUBINS and by Month
        sSQL = "SELECT TOUSeason, TOUBin, Month, Max(KW) AS MaxOfKW, Avg(KW) AS AvgOfKW,
Count(KW) AS NumRecs, Max(FanKW) AS MaxOfFanKW, Avg(FanKW) AS AvgOfFanKW, Max(MotorKW) AS
MaxOfMotorKW, Avg(MotorKW) AS AvgOfMotorKW, Max(VSDKW) AS MaxOfVSDKW, Avg(VSDKW) AS
AvgOfVSDKW, Max(BeltKW) AS MaxOfBeltKW, Avg(BeltKW) AS AvgOfBeltKW FROM " &
sCurrentResultName & " INNER JOIN " & sTempTableName & " ON " & sCurrentResultName &
".DateTime = " & sTempTableName & ".DateTime GROUP BY TOUSeason, TOUBin, Month;"
        Set rstTemp = dbActive.OpenRecordset(sSQL)
    ' Store results
        rstTemp.MoveFirst
        Do While Not rstTemp.EOF
            With rstResultsTOU
                .AddNew
                .Fields("SID").Value = iSID
                .Fields("SGID").Value = iSGID
                .Fields("NumRecs").Value = rstTemp.Fields("NumRecs").Value
                .Fields("TOUSeason").Value = rstTemp.Fields("TOUSeason").Value
                .Fields("TOUBin").Value = rstTemp.Fields("TOUBin").Value
                .Fields("Month").Value = rstTemp.Fields("Month").Value
                .Fields("MaxOfKW").Value = rstTemp.Fields("MaxOfKW").Value
                .Fields("AvgOfKW").Value = rstTemp.Fields("AvgOfKW").Value
                .Fields("MaxOfFanKW").Value = rstTemp.Fields("MaxOfFanKW").Value
                .Fields("AvgOfFanKW").Value = rstTemp.Fields("AvgOfFanKW").Value
                .Fields("MaxOfMotorKW").Value = rstTemp.Fields("MaxOfMotorKW").Value
                .Fields("AvgOfMotorKW").Value = rstTemp.Fields("AvgOfMotorKW").Value
                .Fields("MaxOfBeltKW").Value = rstTemp.Fields("MaxOfBeltKW").Value
                .Fields("AvgOfBeltKW").Value = rstTemp.Fields("AvgOfBeltKW").Value
                .Fields("MaxOfVSDKW").Value = rstTemp.Fields("MaxOfVSDKW").Value
                .Fields("AvgOfVSDKW").Value = rstTemp.Fields("AvgOfVSDKW").Value
                .Update
            End With
            rstTemp.MoveNext
        Loop
    ' Store results
        With rstResultsAnnual
            .AddNew
            .Fields("SID").Value = iSID
            .Fields("SGID").Value = iSGID
     ' Calculate and store Records in surge
            sSQL = "SELECT Count(Surge) AS CountOfSurge FROM " & sCurrentResultName & "
INNER JOIN " & sTempTableName & " ON " & sCurrentResultName & ".DateTime = " &
sTempTableName & ".DateTime GROUP BY Surge HAVING (Surge=True);"
            Set rstTemp = dbActive.OpenRecordset(sSQL)
            If rstTemp.RecordCount > 0 Then
                .Fields("CountOfSurge").Value = rstTemp.Fields("CountOfSurge").Value
            End If
     ' Calculate and store Fan, VSD, Motor, Belt statistics
            sSQL = "SELECT Avg(" & sCurrentResultName & ".FanEff) AS AvgOfFanEff, "
            sSQL = sSQL + "Max(" & sCurrentResultName & ".FanEff) AS MaxOfFanEff, "
            sSQL = sSQL + "Min(" & sCurrentResultName & ".FanEff) AS MinOfFanEff, "
            sSQL = sSQL + "StDev(" & sCurrentResultName & ".FanEff) AS StDevOfFanEff, "
            sSQL = sSQL + "Avg(" & sCurrentResultName & ".MotorEff) AS AvgOfMotorEff, "
            sSQL = sSQL + "Max(" & sCurrentResultName & ".MotorEff) AS MaxOfMotorEff, "
            sSQL = sSQL + "Min(" & sCurrentResultName & ".MotorEff) AS MinOfMotorEff, "
            sSQL = sSQL + "StDev(" & sCurrentResultName & ".MotorEff) AS StDevOfMotorEff,
"
            sSQL = sSQL + "Avg(" & sCurrentResultName & ".VSDEff) AS AvgOfVSDEff, "
            sSQL = sSQL + "Max(" & sCurrentResultName & ".VSDEff) AS MaxOfVSDEff, "
            sSQL = sSQL + "Min(" & sCurrentResultName & ".VSDEff) AS MinOfVSDEff, "
            sSQL = sSQL + "StDev(" & sCurrentResultName & ".VSDEff) AS StDevOfVSDEff, "
            sSQL = sSQL + "Avg(" & sCurrentResultName & ".BeltEff) AS AvgOfBeltEff, "
            sSQL = sSQL + "Max(" & sCurrentResultName & ".BeltEff) AS MaxOfBeltEff, "
            sSQL = sSQL + "Min(" & sCurrentResultName & ".BeltEff) AS MinOfBeltEff, "
            sSQL = sSQL + "StDev(" & sCurrentResultName & ".BeltEff) AS StDevOfBeltEff
FROM " & sCurrentResultName & ";"
            Set rstTemp = dbActive.OpenRecordset(sSQL)
            If rstTemp.RecordCount > 0 Then
                .Fields("AvgOfFanEff").Value = rstTemp.Fields("AvgOfFanEff").Value
                .Fields("MaxOfFanEff").Value = rstTemp.Fields("MaxOfFanEff").Value
```

```
                .Fields("MinOfFanEff").Value = rstTemp.Fields("MinOfFanEff").Value
                .Fields("StDevOfFanEff").Value = rstTemp.Fields("StDevOfFanEff").Value
                .Fields("AvgOfMotorEff").Value = rstTemp.Fields("AvgOfMotorEff").Value
                .Fields("MaxOfMotorEff").Value = rstTemp.Fields("MaxOfMotorEff").Value
                .Fields("MinOfMotorEff").Value = rstTemp.Fields("MinOfMotorEff").Value
                .Fields("StDevOfMotorEff").Value =
rstTemp.Fields("StDevOfMotorEff").Value
                .Fields("AvgOfVSDEff").Value = rstTemp.Fields("AvgOfVSDEff").Value
                .Fields("MaxOfVSDEff").Value = rstTemp.Fields("MaxOfVSDEff").Value
                .Fields("MinOfVSDEff").Value = rstTemp.Fields("MinOfVSDEff").Value
                .Fields("StDevOfVSDEff").Value = rstTemp.Fields("StDevOfVSDEff").Value
                .Fields("AvgOfBeltEff").Value = rstTemp.Fields("AvgOfBeltEff").Value
                .Fields("MaxOfBeltEff").Value = rstTemp.Fields("MaxOfBeltEff").Value
                .Fields("MinOfBeltEff").Value = rstTemp.Fields("MinOfBeltEff").Value
                .Fields("StDevOfBeltEff").Value = rstTemp.Fields("StDevOfBeltEff").Value
            End If
            .Update
            ' need to store date time of run
        End With
        rstScenario.MoveNext
    '    Debug.Print iSID
    Loop

'write the current datetime to the scenario group record to indicate that this scenario
group has been run
rstScenarioGroup.Edit
rstScenarioGroup.Fields("DateRun") = Now
rstScenarioGroup.Update

End If 'this is for whether or not the scenario group has already been run
'end scenario group ID loop, go to next scenario group
rstScenarioGroup.MoveNext
Loop
End Sub
```

Sub ClearRst

```
Sub ClearRst(rstTable As Variant)
    If Not (rstTable.RecordCount = 0) Then
        With rstTable
            .MoveFirst
            While Not .EOF
                .Delete
                .MoveNext
            Wend
        End With
    End If
End Sub
```

Sub CopyTable

```
Sub CopyTable(rstSource As Recordset, sTarget As String)

' Subroutine to create new table with the same fields as an existing table
' rstSource is the existing table that you want to copy
' sTarget is the name of the table with the blank copy of rstSource
Dim dbActive As Database
Dim tdfTarget As TableDef
Dim fldTarget As Field
Dim i As Integer
Set dbActive = CurrentDb()
Set tdfTarget = dbActive.CreateTableDef(sTarget)
For i = 0 To rstSource.Fields.Count - 1
'    Debug.Print i, rstSource.Fields(i).Name, rstSource.Fields(i).Type,
rstSource.Fields(i).Size
    Set fldTarget = tdfTarget.CreateField(rstSource.Fields(i).Name,
rstSource.Fields(i).Type, rstSource.Fields(i).Size)
    tdfTarget.Fields.Append fldTarget
Next
dbActive.TableDefs.Append tdfTarget
End Sub
```

Public Sub DeleteIfExisting

```
Public Sub DeleteIfExisting(sName As String)
Dim dbActive As Database
Dim iLoop As Integer, iCount As Integer
Set dbActive = CurrentDb()
iCount = dbActive.TableDefs.Count
For iLoop = 0 To iCount - 1
```

```
    If dbActive.TableDefs(iLoop).Name = sName Then
        dbActive.TableDefs.Delete (sName)
        Exit For
    End If
Next
End Sub
```

GammaFan Object

```
Option Compare Database
Option Base 1
Option Explicit
' This model was developed by Jeff Stein and Mark Hydeman
' It is of the following form
' Meff=fn(gamma) using a 3rd order polynomial with constant
' where
'   gamma = -log(SCC),
'   SCC = DSP/(cfm^2), and
'   BHP = CFM * DSP/(6350 * Meff)
Const cbMessage = False ' Turns on dialog boxes
Dim iFanID As Integer
Dim dGammaSurge As Double
Dim iSurgeFDID As Integer, iLowFDID As Integer, iHighFDID As Integer
Dim dCVRMSE As Double, dMBE As Double, dR2S As Double, dR2N As Double
Dim dR2PS As Double, dR2PN As Double
Dim iNumRecs As Integer, iNumRecsN As Integer, iNumRecsS As Integer
Dim iNumRecsPN As Integer, iNumRecsPS As Integer
Dim iLowRPMFDID As Integer, iHighRPMFDID As Integer
Dim dN0 As Double, dN1 As Double, dN2 As Double, dN3 As Double, dDia As Double
Dim dS0 As Double, dS1 As Double, dS2 As Double, dS3 As Double
Dim dPN0 As Double, dPN1 As Double, dPN2 As Double, dPN3 As Double
Dim dPS0 As Double, dPS1 As Double, dPS2 As Double, dPS3 As Double
Property Let FanID(iFanIDV As Integer)
    iFanID = iFanIDV
End Property
Property Let SurgeFDID(iSurgeFDIDV As Integer)
    iSurgeFDID = iSurgeFDIDV
End Property
Property Let LowFDID(iLowFDIDV As Integer)
    iLowFDID = iLowFDIDV
End Property
Property Let HighFDID(iHighFDIDV As Integer)
    iHighFDID = iHighFDIDV
End Property
Property Let LowRPMFDID(iLowRPMFDIDV As Integer)
    iLowRPMFDID = iLowRPMFDIDV
End Property
Property Let HighRPMFDID(iHighRPMFDIDV As Integer)
    iHighRPMFDID = iHighRPMFDIDV
End Property
Property Let NumRecs(iNumRecsV As Integer)
    iNumRecs = iNumRecsV
End Property
Property Let NumRecsN(iNumRecsNV As Integer)
    iNumRecsN = iNumRecsNV
End Property
Property Let NumRecsS(iNumRecsSV As Integer)
    iNumRecsS = iNumRecsSV
End Property
Property Let NumRecsPN(iNumRecsPNV As Integer)
    iNumRecsPN = iNumRecsPNV
End Property
Property Let NumRecsPS(iNumRecsPSV As Integer)
    iNumRecsPS = iNumRecsPSV
End Property
Property Let DIA(dDIAV As Double)
    dDia = dDIAV
End Property
Property Let GammaSurge(dGammaSurgeV As Double)
    dGammaSurge = dGammaSurgeV
End Property
Property Let CVRMSE(dCVRMSEV As Double)
    dCVRMSE = dCVRMSEV
End Property
Property Let MBE(dMBEV As Double)
    dMBE = dMBEV
End Property
Property Let R2N(dR2NV As Double)
    dR2N = dR2NV
```

```
End Property
Property Let R2S(dR2SV As Double)
    dR2S = dR2SV
End Property
Property Let N0(dN0V As Double)
    dN0 = dN0V
End Property
Property Let N1(dN1V As Double)
    dN1 = dN1V
End Property
Property Let N2(dN2V As Double)
    dN2 = dN2V
End Property
Property Let N3(dN3V As Double)
    dN3 = dN3V
End Property
Property Let S0(dS0V As Double)
    dS0 = dS0V
End Property
Property Let S1(dS1V As Double)
    dS1 = dS1V
End Property
Property Let S2(dS2V As Double)
    dS2 = dS2V
End Property
Property Let S3(dS3V As Double)
    dS3 = dS3V
End Property
Property Let R2PN(dR2PNV As Double)
    dR2PN = dR2PNV
End Property
Property Let R2PS(dR2PSV As Double)
    dR2PS = dR2PSV
End Property
Property Let PN0(dPN0V As Double)
    dPN0 = dPN0V
End Property
Property Let PN1(dPN1V As Double)
    dPN1 = dPN1V
End Property
Property Let PN2(dPN2V As Double)
    dPN2 = dPN2V
End Property
Property Let PN3(dPN3V As Double)
    dPN3 = dPN3V
End Property
Property Let PS0(dPS0V As Double)
    dPS0 = dPS0V
End Property
Property Let PS1(dPS1V As Double)
    dPS1 = dPS1V
End Property
Property Let PS2(dPS2V As Double)
    dPS2 = dPS2V
End Property
Property Let PS3(dPS3V As Double)
    dPS3 = dPS3V
End Property
Property Get FanID() As Integer
    FanID = iFanID
End Property
Property Get SurgeFDID() As Integer
    SurgeFDID = iSurgeFDID
End Property
Property Get LowFDID() As Integer
    LowFDID = iLowFDID
End Property
Property Get HighFDID() As Integer
    HighFDID = iHighFDID
End Property
Property Get LowRPMFDID() As Integer
    LowRPMFDID = iLowRPMFDID
End Property
Property Get HighRPMFDID() As Integer
    HighRPMFDID = iHighRPMFDID
End Property
Property Get NumRecs() As Integer
    NumRecs = iNumRecs
End Property
Property Get NumRecsN() As Integer
```

```
    NumRecsN = iNumRecsN
End Property
Property Get NumRecsS() As Integer
    NumRecsS = iNumRecsS
End Property
Property Get NumRecsPN() As Integer
    NumRecsPN = iNumRecsPN
End Property
Property Get NumRecsPS() As Integer
    NumRecsPS = iNumRecsPS
End Property
Property Get DIA() As Double
    DIA = dDia
End Property
Property Get GammaSurge() As Double
    GammaSurge = dGammaSurge
End Property
Property Get CRMSE() As Double
    CRMSE = dCRMSE
End Property
Property Get MBE() As Double
    MBE = dMBE
End Property
Property Get R2N() As Double
    R2N = dR2N
End Property
Property Get R2S() As Double
    R2S = dR2S
End Property
Property Get N0() As Double
    N0 = dN0
End Property
Property Get N1() As Double
    N1 = dN1
End Property
Property Get N2() As Double
    N2 = dN2
End Property
Property Get N3() As Double
    N3 = dN3
End Property
Property Get S0() As Double
    S0 = dS0
End Property
Property Get S1() As Double
    S1 = dS1
End Property
Property Get S2() As Double
    S2 = dS2
End Property
Property Get S3() As Double
    S3 = dS3
End Property
Property Get R2PN() As Double
    R2PN = dR2PN
End Property
Property Get R2PS() As Double
    R2PS = dR2PS
End Property
Property Get PN0() As Double
    PN0 = dPN0
End Property
Property Get PN1() As Double
    PN1 = dPN1
End Property
Property Get PN2() As Double
    PN2 = dPN2
End Property
Property Get PN3() As Double
    PN3 = dPN3
End Property
Property Get PS0() As Double
    PS0 = dPS0
End Property
Property Get PS1() As Double
    PS1 = dPS1
End Property
Property Get PS2() As Double
    PS2 = dPS2
End Property
```

```
Property Get PS3() As Double
    PS3 = dPS3
End Property
```

Sub xsMakeFan

```
Sub xsMakeFan(rstData As Recordset, rstHeader As Recordset)
' Subroutine to make fan models from data in tables
' FanData and FanHeader
' This routine uses the model developed by Jeff Stein and Mark Hydeman
' It is of the following form
' Meff=fn(gamma) using a 3rd order polynomial with constant and
' Mphi=fn(eff) using a 3rd order polynomial with constant
' where
'   gamma = -log(SCC),
'   SCC = DSP/(cfm^2), and
'   BHP = CFM * DSP/(6350 * Meff)
'   phi = CFM/(RPM*Diam^3)
' Note it is critical that you include the peak efficiency point in both the surge and
non-surge regions
' Failure to do so causes you to extrapolate between the points between where the two
curves meet
Dim dbActive As Database
Dim rstDataTemp As Recordset
Dim i As Integer, j As Integer
Dim iFanID As Integer, iSurgeFDID As Integer
Dim dData() As Variant, dCoefs As Variant
Dim dX As Double, dDia As Double
Dim x() As Variant, y() As Variant
Dim dGammaSurge As Double
Dim qQDTemp As QueryDef
Dim sQDTemp As String
Dim iNumRecs As Integer
Dim sQDName As String, sDataName As String
Dim bMessage As Boolean
Set dbActive = CurrentDb()
' Set the name for the temporary query
' sQDName = "TEMP"
iFanID = rstHeader.Fields("FanID").Value
Me.FanID = iFanID
dDia = rstHeader.Fields("DIA").Value
Me.DIA = dDia
sDataName = rstData.Name
' Calculate and record Gamma, Phi, SCC, Efficiency and critical IDs from data
sQDTemp = "SELECT FDID,  CFM, RPM, DP, BHP, Gamma, Phi, SCC, EFF, EFFPred, BHPPred,
BHPError"
sQDTemp = sQDTemp & " FROM " & sDataName & " WHERE FanID="
sQDTemp = sQDTemp & iFanID
'Set qQDTemp = dbActive.CreateQueryDef()
'qQDTemp.Name = sQDName 'This is a temp query (not stored)
'qQDTemp.SQL = sQDTemp
'Call DeleteIfExistingQD(sQDName)
'dbActive.QueryDefs.Append qQDTemp
'    qQDTemp.Execute
'Set rstData = qQDTemp.OpenRecordset(dbOpenDynaset)
Set rstDataTemp = dbActive.OpenRecordset(sQDTemp)
'    Set rstDataOneFan = qQDTemp.OpenRecordset(dbOpenDynaset)
rstDataTemp.MoveLast
rstDataTemp.MoveFirst
' Make intermediate values of SCC, Gamma and EFF
Call xpsMakeGammaAndPhi(rstDataTemp, rstHeader)
' Record GammaSurge
dGammaSurge = Me.GammaSurge
rstDataTemp.Close
' Normal Model Data Gamma (Gamma>=Gamma Surge)
sQDTemp = "SELECT Gamma, EFF"
sQDTemp = sQDTemp & " FROM " & sDataName & " WHERE ((FanID="
sQDTemp = sQDTemp & iFanID & ") AND (Gamma>="
sQDTemp = sQDTemp & dGammaSurge & "))"
'Set qQDTemp = dbActive.CreateQueryDef()
'qQDTemp.Name = sQDName 'This is a temp query (not stored)
'qQDTemp.SQL = sQDTemp
'Call DeleteIfExistingQD(sQDName)
'dbActive.QueryDefs.Append qQDTemp
'    qQDTemp.Execute
'Set rstData = qQDTemp.OpenRecordset(dbOpenSnapshot)
Set rstDataTemp = dbActive.OpenRecordset(sQDTemp)
rstDataTemp.MoveLast
rstDataTemp.MoveFirst
Call xpsSolveNormal(rstDataTemp, rstHeader)
rstDataTemp.Close
```

```
' Normal Model Data Phi (Gamma>=Gamma Surge and RPM is not null)
sQDTemp = "SELECT EFF, Phi"
sQDTemp = sQDTemp & " FROM " & sDataName & " WHERE ((FanID="
sQDTemp = sQDTemp & iFanID & ") AND (Gamma>="
sQDTemp = sQDTemp & dGammaSurge & ") AND (Not isnull(RPM)))"
'Set qQDTemp = dbActive.CreateQueryDef()
'qQDTemp.Name = sQDName 'This is a temp query (not stored)
'qQDTemp.SQL = sQDTemp
'Call DeleteIfExistingQD(sQDName)
'dbActive.QueryDefs.Append qQDTemp
'    qQDTemp.Execute
'Set rstData = qQDTemp.OpenRecordset(dbOpenSnapshot)
Set rstDataTemp = dbActive.OpenRecordset(sQDTemp)
If Not rstDataTemp.EOF Then
    rstDataTemp.MoveLast
    rstDataTemp.MoveFirst
    Call xpsSolvePhiNormal(rstDataTemp, rstHeader)
End If
rstDataTemp.Close
' Surge Model Data Gamma (Gamma<=GammaSurge)
sQDTemp = "SELECT Gamma, EFF"
sQDTemp = sQDTemp & " FROM " & sDataName & " WHERE ((FanID="
sQDTemp = sQDTemp & iFanID & ") AND (Gamma<="
sQDTemp = sQDTemp & dGammaSurge & "))"
'Set qQDTemp = dbActive.CreateQueryDef()
'qQDTemp.Name = sQDName 'This is a temp query (not stored)
'qQDTemp.SQL = sQDTemp
'Call DeleteIfExistingQD(sQDName)
'dbActive.QueryDefs.Append qQDTemp
'    qQDTemp.Execute
'Set rstData = qQDTemp.OpenRecordset(dbOpenSnapshot)
Set rstDataTemp = dbActive.OpenRecordset(sQDTemp)
rstDataTemp.MoveLast
rstDataTemp.MoveFirst
Call xpsSolveSurge(rstDataTemp, rstHeader)
rstDataTemp.Close
' Surge Model Data Phi (Gamma<=GammaSurge and not isnull(RPM))
sQDTemp = "SELECT EFF, Phi"
sQDTemp = sQDTemp & " FROM " & sDataName & " WHERE ((FanID="
sQDTemp = sQDTemp & iFanID & ") AND (Gamma<="
sQDTemp = sQDTemp & dGammaSurge & ") and (NOT ISNULL(RPM)))"
'Set qQDTemp = dbActive.CreateQueryDef()
'qQDTemp.Name = sQDName 'This is a temp query (not stored)
'qQDTemp.SQL = sQDTemp
'Call DeleteIfExistingQD(sQDName)
'dbActive.QueryDefs.Append qQDTemp
'    qQDTemp.Execute
'Set rstData = qQDTemp.OpenRecordset(dbOpenSnapshot)
Set rstDataTemp = dbActive.OpenRecordset(sQDTemp)
If Not rstDataTemp.EOF Then
    rstDataTemp.MoveLast
    rstDataTemp.MoveFirst
    Call xpsSolvePhiSurge(rstDataTemp, rstHeader)
End If
rstDataTemp.Close
' Calculate Results
sQDTemp = "SELECT FDID, RPM, CFM, DP, BHP, Gamma, SCC, Phi,"
sQDTemp = sQDTemp & "EFF, EFFPred, BHPPred, BHPError, PhiPred, PhiError"
sQDTemp = sQDTemp & " FROM " & sDataName & " WHERE FanID="
sQDTemp = sQDTemp & iFanID
'Set qQDTemp = dbActive.CreateQueryDef()
'qQDTemp.Name = sQDName 'This is a temp query (not stored)
'qQDTemp.SQL = sQDTemp
'Call DeleteIfExistingQD(sQDName)
'dbActive.QueryDefs.Append qQDTemp
'    qQDTemp.Execute
'Set rstData = qQDTemp.OpenRecordset(dbOpenDynaset)
Set rstDataTemp = dbActive.OpenRecordset(sQDTemp)
rstDataTemp.MoveLast
rstDataTemp.MoveFirst
Call xpsGetFan(rstDataTemp, rstHeader)
rstDataTemp.Close
'Call DeleteIfExistingQD(sQDName)
End Sub


Private Sub xpsSolveNormal(rstDataOneFan As Recordset, rstHeader As Recordset)
' Subroutine to solve a third order function  of efficiency as a function of gamma in the
normal region
' Note this table should be filtered to have only one fan's data in the normal region
```

```
' This routine uses the model developed by Jeff Stein and Mark Hydeman
' It is of the following form
' Meff=fn(gamma) using a 3rd order polynomial with constant
' where
'    gamma = -log(SCC),
'    SCC = DSP/(cfm^2), and
'    BHP = CFM * DSP/(6350 * Meff)
Dim i As Integer, j As Integer
Dim iFanID As Integer, iSurgeFDID As Integer
Dim dData() As Variant, dCoefs As Variant
Dim dX As Double
Dim x() As Variant, y() As Variant
' Store the number of normal records
Me.NumRecsN = rstDataOneFan.RecordCount
If rstDataOneFan.RecordCount >= 4 Then
    ' Solve for coefficients
    ' Normal operation
    ReDim x(1 To 3, 1 To rstDataOneFan.RecordCount)
    ReDim y(1 To rstDataOneFan.RecordCount)
    i = 1
    ' Fill the Arrays for Linest
    While Not rstDataOneFan.EOF
        dX = rstDataOneFan.Fields(0).Value
        x(1, i) = dX
        x(2, i) = dX ^ 2
        x(3, i) = dX ^ 3
        y(i) = rstDataOneFan.Fields(1).Value
        rstDataOneFan.MoveNext
        i = i + 1
    Wend
' Calculate coefficients
    dCoefs = Excel.WorksheetFunction.LinEst(y, x, "true", "true")
    ' Store coefficients in header
    With rstHeader
        .Edit
        .Fields("N0").Value = dCoefs(1, 4)
        .Fields("N1").Value = dCoefs(1, 3)
        .Fields("N2").Value = dCoefs(1, 2)
        .Fields("N3").Value = dCoefs(1, 1)
        .Update
    End With
    ' Store coefficients in object
    Me.N0 = dCoefs(1, 4)
    Me.N1 = dCoefs(1, 3)
    Me.N2 = dCoefs(1, 2)
    Me.N3 = dCoefs(1, 1)
    Me.R2N = dCoefs(3, 1) ' R2 Error
Else
    If cbMessage Then _
    MsgBox "Error on fan #" & rstHeader.Fields("FanID").Value & ".  Not enough normal
data for the model.  You must have at least 4 points."
End If
End Sub
Private Sub xpsSolveSurge(rstDataOneFan As Recordset, rstHeader As Recordset)
' Subroutine to solve a third order function  of efficiency as a function of gamma in the
Surge region
' Note this table should be filtered to have only one fan's data in the Surge region
' This routine uses the model developed by Jeff Stein and Mark Hydeman
' It is of the following form
' Meff=fn(gamma) using a 3rd order polynomial with constant
' where
'    gamma = -log(SCC),
'    SCC = DSP/(cfm^2), and
'    BHP = CFM * DSP/(6350 * Meff)
Dim i As Integer, j As Integer
Dim iFanID As Integer, iSurgeFDID As Integer
Dim dData() As Variant, dCoefs As Variant
Dim dX As Double
Dim x() As Variant, y() As Variant
' Store the number of surge records
Me.NumRecsS = rstDataOneFan.RecordCount
If rstDataOneFan.RecordCount >= 4 Then
    ' Solve for coefficients
    ' Surge operation
    ReDim x(1 To 3, 1 To rstDataOneFan.RecordCount)
    ReDim y(1 To rstDataOneFan.RecordCount)
    i = 1
    ' Fill the Arrays for Linest
    While Not rstDataOneFan.EOF
        dX = rstDataOneFan.Fields(0).Value
```

```
        x(1, i) = dX
        x(2, i) = dX ^ 2
        x(3, i) = dX ^ 3
        y(i) = rstDataOneFan.Fields(1).Value
        rstDataOneFan.MoveNext
        i = i + 1
    Wend
    ' Calculate coefficients
    dCoefs = Excel.WorksheetFunction.LinEst(y, x, "true", "true")
    ' Store coefficients in header
    With rstHeader
        .Edit
        .Fields("S0").Value = dCoefs(1, 4)
        .Fields("S1").Value = dCoefs(1, 3)
        .Fields("S2").Value = dCoefs(1, 2)
        .Fields("S3").Value = dCoefs(1, 1)
        .Update
    End With
    ' Store coefficients in object
    Me.S0 = dCoefs(1, 4)
    Me.S1 = dCoefs(1, 3)
    Me.S2 = dCoefs(1, 2)
    Me.S3 = dCoefs(1, 1)
    Me.R2S = dCoefs(3, 1) ' R2 Error
Else
    If cbMessage Then _
    MsgBox "Error on fan #" & rstHeader.Fields("FanID").Value & ".  Not enough Surge data
for the model.  You must have at least 4 points."
End If
End Sub
Private Sub xpsSolvePhiNormal(rstDataOneFan As Recordset, rstHeader As Recordset)
' Subroutine to solve a third order function  of Phi as a function of efficiency in the
normal region
' Note this table should be filtered to have only one fan's data in the normal region
' This routine uses the model developed by Jeff Stein and Mark Hydeman
' It is of the following form
' MPhi=fn(eff) using a 3rd order polynomial with constant
' where
'    Phi = CFM/(DIAM * RPM^3)
Dim i As Integer, j As Integer
Dim iFanID As Integer, iSurgeFDID As Integer
Dim dData() As Variant, dCoefs As Variant
Dim dX As Double
Dim x() As Variant, y() As Variant
' Store the number of normal records
Me.NumRecsPN = rstDataOneFan.RecordCount
If rstDataOneFan.RecordCount >= 4 Then
    ' Solve for coefficients
    ' Normal operation
    ReDim x(1 To 3, 1 To rstDataOneFan.RecordCount)
    ReDim y(1 To rstDataOneFan.RecordCount)
    i = 1
    ' Fill the Arrays for Linest
    While Not rstDataOneFan.EOF
        dX = rstDataOneFan.Fields(0).Value
        x(1, i) = dX
        x(2, i) = dX ^ 2
        x(3, i) = dX ^ 3
        y(i) = rstDataOneFan.Fields(1).Value
        rstDataOneFan.MoveNext
        i = i + 1
    Wend
' Calculate coefficients
    dCoefs = Excel.WorksheetFunction.LinEst(y, x, "true", "true")
    ' Store coefficients in header
    With rstHeader
        .Edit
        .Fields("PN0").Value = dCoefs(1, 4)
        .Fields("PN1").Value = dCoefs(1, 3)
        .Fields("PN2").Value = dCoefs(1, 2)
        .Fields("PN3").Value = dCoefs(1, 1)
        .Update
    End With
    ' Store coefficients in object
    Me.PN0 = dCoefs(1, 4)
    Me.PN1 = dCoefs(1, 3)
    Me.PN2 = dCoefs(1, 2)
    Me.PN3 = dCoefs(1, 1)
    Me.R2PN = dCoefs(3, 1) ' R2 Error
Else
```

```
    If cbMessage Then _
    MsgBox "Error on fan #" & rstHeader.Fields("FanID").Value & ".  Not enough normal
data for the PHI model.  You must have at least 4 points."
End If
End Sub
Private Sub xpsSolvePhiSurge(rstDataOneFan As Recordset, rstHeader As Recordset)
' Subroutine to solve a third order function  of Phi as a function of efficiency in the
Surge region
' Note this table should be filtered to have only one fan's data in the Surge region
' This routine uses the model developed by Jeff Stein and Mark Hydeman
' It is of the following form
' MPhi=fn(eff) using a 3rd order polynomial with constant
' where
'    Phi = CFM/(DIAM * RPM^3)
Dim i As Integer, j As Integer
Dim iFanID As Integer, iSurgeFDID As Integer
Dim dData() As Variant, dCoefs As Variant
Dim dX As Double
Dim x() As Variant, y() As Variant
' Store the number of surge records
Me.NumRecsPS = rstDataOneFan.RecordCount
If rstDataOneFan.RecordCount >= 4 Then
    ' Solve for coefficients
    ' Surge operation
    ReDim x(1 To 3, 1 To rstDataOneFan.RecordCount)
    ReDim y(1 To rstDataOneFan.RecordCount)
    i = 1
    ' Fill the Arrays for Linest
    While Not rstDataOneFan.EOF
        dX = rstDataOneFan.Fields(0).Value
        x(1, i) = dX
        x(2, i) = dX ^ 2
        x(3, i) = dX ^ 3
        y(i) = rstDataOneFan.Fields(1).Value
        rstDataOneFan.MoveNext
        i = i + 1
    Wend
    ' Calculate coefficients
    dCoefs = Excel.WorksheetFunction.LinEst(y, x, "true", "true")
    ' Store coefficients in header
    With rstHeader
        .Edit
        .Fields("PS0").Value = dCoefs(1, 4)
        .Fields("PS1").Value = dCoefs(1, 3)
        .Fields("PS2").Value = dCoefs(1, 2)
        .Fields("PS3").Value = dCoefs(1, 1)
        .Update
    End With
    ' Store coefficients in object
    Me.PS0 = dCoefs(1, 4)
    Me.PS1 = dCoefs(1, 3)
    Me.PS2 = dCoefs(1, 2)
    Me.PS3 = dCoefs(1, 1)
    Me.R2PS = dCoefs(3, 1) ' R2 Error
Else
    If cbMessage Then _
    MsgBox "Error on fan #" & rstHeader.Fields("FanID").Value & ".  Not enough Surge data
for the Phi model.  You must have at least 4 points."
End If
End Sub
Private Sub xpsMakeGammaAndPhi(rstDataOneFan As Recordset, rstHeader)
' Subroutine to calculate and record the intermediate values for
' the new fan model:
'    SCC: The system curve coefficient defined as DP/(CFM^2)
'    Gamma: -Log(SCC)
'    EFF: The mechanical efficiency of the fan calculated from CFM, DP and BHP
' This routine also tracks and records the following values for each fan
'    GammaLow: The minimum Gamma for the dataset
'    GammaHigh: The maximum Gamma for the dataset
'    GammaSurge: The Gamma at the highest efficiency in the dataset
' Gamma surge is intepreted as the edge of the surge region
Dim bLoop As Boolean
Dim i As Integer
Dim iFDID As Integer
Dim dGammaLow As Double, dGammaHigh As Double, dEFFHigh As Double
Dim dGammaLowRPM As Double, dGammaHighRPM As Double
Dim dSCC As Double, dEff As Double, dBHP As Double
Dim dRPM As Double
Dim dGamma As Double, dCFM As Double, dDP As Double, dPhi As Double
Dim bFirst As Boolean, bRPM As Boolean
```

```
Me.NumRecs = rstDataOneFan.RecordCount
bFirst = True
Do
    ' Read data
    dCFM = rstDataOneFan.Fields("CFM").Value
    dDP = rstDataOneFan.Fields("DP").Value
    dBHP = rstDataOneFan.Fields("BHP").Value
    iFDID = rstDataOneFan.Fields("FDID").Value
    bRPM = Not IsNull(rstDataOneFan.Fields("RPM").Value)
    ' Calculate values for SCC, Gamma and Efficiency
    dSCC = dDP / (dCFM ^ 2)
    dGamma = -1 * Log(dSCC)
    dEff = dCFM * dDP / (6350 * dBHP)
    ' Store values for SCC, Gamma and Efficiency
    With rstDataOneFan
        .Edit
        .Fields("SCC").Value = dSCC
        .Fields("Gamma").Value = dGamma
        .Fields("EFF").Value = dEff
    ' Calculate and store PHI if there is RPM data
        If bRPM Then
            dRPM = rstDataOneFan.Fields("RPM").Value
            dPhi = dCFM / (dRPM * Me.DIA ^ 3)
            .Fields("Phi").Value = dPhi
        End If
        .Update
    End With
    ' Track critical values
    If bFirst Then
        ' Store the first values
        Me.LowFDID = iFDID
        Me.HighFDID = iFDID
        Me.LowRPMFDID = iFDID
        Me.HighRPMFDID = iFDID
        Me.SurgeFDID = iFDID
        Me.GammaSurge = dGamma
        dGammaLow = dGamma
        dGammaHigh = dGamma
        dGammaLowRPM = dGamma
        dGammaHighRPM = dGamma
        dEFFHigh = dEff
        bFirst = False
    End If
    If dGamma < dGammaLow Then
        ' New low Gamma
        Me.LowFDID = iFDID
        dGammaLow = dGamma
    End If
    If dGamma > dGammaHigh Then
        ' New high Gamma
        Me.HighFDID = iFDID
        dGammaHigh = dGamma
    End If
    If dGamma < dGammaLowRPM And bRPM Then
        ' New low Gamma with RPM
        Me.LowRPMFDID = iFDID
        dGammaLowRPM = dGamma
    End If
    If dGamma > dGammaHighRPM And bRPM Then
        ' New high Gamma with RPM
        Me.HighRPMFDID = iFDID
        dGammaHighRPM = dGamma
    End If
    If dEff > dEFFHigh Then
        ' New critical Gamma
        Me.SurgeFDID = iFDID
        Me.GammaSurge = dGamma
        dEFFHigh = dEff
    End If
    rstDataOneFan.MoveNext
    bLoop = Not rstDataOneFan.EOF
Loop Until Not bLoop
With rstHeader
    .Edit
    .LowFDID = Me.LowFDID
    .HighFDID = Me.HighFDID
    .SurgeFDID = Me.SurgeFDID
    .LowRPMFDID = Me.LowRPMFDID
    .HighRPMFDID = Me.HighRPMFDID
    .Update
```

```
End With
End Sub
Private Sub xpsGetFan(rstDataOneFan As Recordset, rstHeader As Recordset)
' Subroutine to calculate and record the following:
'   EFFpred: the predicted efficiency from the Gamma model
'   BHPpred: the predicted BHP from the Gamma model
' This subroutine also calculates and records the CVRMSE and MBE for both the
' Normal and Surge region data.
Dim dEFFPred As Double, dBHPPred As Double
Dim bLoop As Boolean, bNormal As Boolean, bSurge As Boolean
Dim bNormalPhi As Boolean, bSurgePhi As Boolean, bRPM As Boolean
Dim iFanID As Integer, i As Integer
Dim dTempN As Double, dTempS As Double
Dim dGamma As Double, dCFM As Double, dDP As Double, dBHP As Double
Dim dEff As Double, dPhi As Double, dPhiPred As Double
Dim dNError As Double, dNSumError As Double, dNSumError2 As Double, dNSumBHP As Double
Dim dSError As Double, dSSumError As Double, dSSumError2 As Double, dSSumBHP As Double
Dim dPNError As Double, dPNSumError As Double, dPNSumError2 As Double, dPNSumPHI As
Double
Dim dPSError As Double, dPSSumError As Double, dPSSumError2 As Double, dPSSumPHI As
Double
bNormal = Me.NumRecsN >= 4
bSurge = Me.NumRecsS >= 4
bNormalPhi = Me.NumRecsPN >= 4
bSurgePhi = Me.NumRecsPS >= 4
iFanID = Me.FanID
Do
    dGamma = rstDataOneFan.Fields("Gamma").Value
    dCFM = rstDataOneFan.Fields("CFM").Value
    dDP = rstDataOneFan.Fields("DP").Value
    dBHP = rstDataOneFan.Fields("BHP").Value
    bRPM = Not IsNull(rstDataOneFan.Fields("RPM").Value)
    If dGamma >= Me.GammaSurge Then
        'Normal region
        If bNormal Then
            ' Calculate Efficiency and BHP
            dEFFPred = Me.N0 + Me.N1 * dGamma _
                + Me.N2 * dGamma ^ 2 + Me.N3 * dGamma ^ 3
            dBHPPred = dCFM * dDP / (6350 * dEFFPred)
            ' Calculate fit statistics
            dNError = dBHPPred - dBHP
            dNSumError = dNSumError + dNError
            dNSumError2 = dNSumError2 + dNError ^ 2
            dNSumBHP = dNSumBHP + dBHP
            ' Record results
            With rstDataOneFan
                .Edit
                .Fields("EFFPred").Value = dEFFPred
                .Fields("BHPPred").Value = dBHPPred
                .Fields("BHPError").Value = (dBHPPred - dBHP) / dBHP
                .Update
            End With
            If bRPM Then ' Calculate and store Phi
                dEff = rstDataOneFan.Fields("EFF").Value
                dPhi = rstDataOneFan.Fields("Phi").Value
                ' Calculate Phi
                dPhiPred = Me.PN0 + Me.PN1 * dEff _
                    + Me.PN2 * dEff ^ 2 + Me.PN3 * dEff ^ 3
                ' Calculate fit statistics
                dPNError = dPhiPred - dPhi
                dPNSumError = dPNSumError + dPNError
                dPNSumError2 = dPNSumError2 + dPNError ^ 2
                dPNSumPHI = dPNSumPHI + dPhi
                With rstDataOneFan
                    .Edit
                    .Fields("PhiPred").Value = dPhiPred
                    .Fields("PhiError").Value = (dPhiPred - dPhi) / dPhi
                    .Update
                End With
            End If 'RPM
        End If
    Else
        'Surge region
        If bSurge Then
            ' Calculate Efficiency and BHP
            dEFFPred = Me.S0 + Me.S1 * dGamma _
                + Me.S2 * dGamma ^ 2 + Me.S3 * dGamma ^ 3
            dBHPPred = dCFM * dDP / (6350 * dEFFPred)
            ' Calculate fit statistics
            dSError = dBHPPred - dBHP
```

```
            dSSumError = dSSumError + dSError
            dSSumError2 = dSSumError2 + dSError ^ 2
            dSSumBHP = dSSumBHP + dBHP
            ' Record results
            With rstDataOneFan
                .Edit
                .Fields("EFFPred").Value = dEFFPred
                .Fields("BHPPred").Value = dBHPPred
                .Fields("BHPError").Value = (dBHPPred - dBHP) / dBHP
                .Update
            End With
            If bRPM Then ' Calculate and store Phi
                dEff = rstDataOneFan.Fields("EFF").Value
                dPhi = rstDataOneFan.Fields("Phi").Value
                ' Calculate Phi
                dPhiPred = Me.PS0 + Me.PS1 * dEff _
                    + Me.PS2 * dEff ^ 2 + Me.PS3 * dEff ^ 3
                ' Calculate fit statistics
                dPSError = dPhiPred - dPhi
                dPSSumError = dPSSumError + dPSError
                dPSSumError2 = dPSSumError2 + dPSError ^ 2
                dPSSumPHI = dPSSumPHI + dPhi
                With rstDataOneFan
                    .Edit
                    .Fields("PhiPred").Value = dPhiPred
                    .Fields("PhiError").Value = (dPhiPred - dPhi) / dPhi
                    .Update
                End With
            End If 'RPM
        End If
    End If
    rstDataOneFan.MoveNext
Loop Until rstDataOneFan.EOF
With rstHeader
    .Edit
    If bSurge Then
        .Fields("SCVRMSE").Value = (Sqr(dSSumError2 / Me.NumRecsS)) / (dSSumBHP /
Me.NumRecsS)
        .Fields("SMBE").Value = dSSumError / dSSumBHP
    End If
    .Fields("SNumRecords").Value = Me.NumRecsS
    If bNormal Then
        .Fields("NCVRMSE").Value = (Sqr(dNSumError2 / Me.NumRecsN)) / (dNSumBHP /
Me.NumRecsN)
        .Fields("NMBE").Value = dNSumError / dNSumBHP
    End If
    .Fields("NNumRecords").Value = Me.NumRecsN
    If bSurgePhi Then
        .Fields("PSCVRMSE").Value = (Sqr(dPSSumError2 / Me.NumRecsPS)) / (dPSSumPHI /
Me.NumRecsPS)
        .Fields("PSMBE").Value = dPSSumError / dPSSumPHI
    End If
    .Fields("PSNumRecords").Value = Me.NumRecsPS
    If bNormalPhi Then
        .Fields("PNCVRMSE").Value = (Sqr(dPNSumError2 / Me.NumRecsPN)) / (dPNSumPHI /
Me.NumRecsPN)
        .Fields("PNMBE").Value = dPNSumError / dPNSumPHI
    End If
    .Fields("PNNumRecords").Value = Me.NumRecsPN
    .Update
End With
End Sub
```

Function xfEff

```
Function xfEff(dCFM As Double, dDP As Double) As Double
' Function to calculate efficiency as a function of cfm and static pressure
' using the gamma model
' The Gamma Fan Model must be subtantiated for this function to work
Dim dGamma As Double
dGamma = xfGamma(dCFM, dDP)
If dGamma >= Me.GammaSurge Then
    ' Normal Region
    ' Calculate Efficiency and BHP
    xfEff = Me.N0 + Me.N1 * dGamma _
        + Me.N2 * dGamma ^ 2 + Me.N3 * dGamma ^ 3
Else
    'Surge region
    ' Calculate Efficiency and BHP
    xfEff = Me.S0 + Me.S1 * dGamma _
```

```
        + Me.S2 * dGamma ^ 2 + Me.S3 * dGamma ^ 3
End If
End Function
```

Function xfGamma

```
Function xfGamma(dCFM As Double, dDP As Double) As Double
' Function to calculate gamma as a function of cfm and static pressure
'Dim dSCC As Double
'dSCC = dDP / (dCFM ^ 2)
xfGamma = -1 * Log(Me.xfSCC(dCFM, dDP))
End Function
```

Function xfSCC

```
Function xfSCC(dCFM As Double, dDP As Double) As Double
' Function to calculate gamma as a function of cfm and static pressure
xfSCC = dDP / (dCFM ^ 2)
End Function
```

Function xfPhi

```
Function xfPhi(dFanEff As Double, dCFM As Double, dDP As Double) As Double
' Function to calculate Phi as a function of efficiency
'Needs to know CFM and DP to decide which set of coefficients to use
Dim dGamma As Double
dGamma = xfGamma(dCFM, dDP)

If dGamma >= Me.GammaSurge Then
    ' Normal Region Calculate Phi
    xfPhi = Me.PN0 + Me.PN1 * dFanEff _
        + Me.PN2 * dFanEff ^ 2 + Me.PN3 * dFanEff ^ 3
Else
    'Surge region Calculate Phi
    xfPhi = Me.PS0 + Me.PS1 * dFanEff _
        + Me.PS2 * dFanEff ^ 2 + Me.PS3 * dFanEff ^ 3
End If


End Function
```

Function xfRPM

```
Function xfRPM(dPhi As Double, dCFM As Double) As Double
' Function to calculate Phi as a function of efficiency
            'calc RPM from Phi
            xfRPM = dCFM / (dPhi * Me.DIA ^ 3)
End Function
```

Sub xsGetFan

```
Sub xsGetFan(rstHeader As Recordset, rstDataOneFan As Recordset)
Dim i As Integer, iFanID As Integer
With rstHeader
    iFanID = .Fields("FanID").Value
    Me.FanID = .Fields("FanID").Value
    Me.DIA = .Fields("Dia").Value
    Me.LowFDID = .Fields("LowFDID").Value
    Me.HighFDID = .Fields("HighFDID").Value
    Me.LowRPMFDID = .Fields("LowRPMFDID").Value
    Me.HighRPMFDID = .Fields("HighRPMFDID").Value
    Me.SurgeFDID = .Fields("SurgeFDID").Value
    Me.N0 = .Fields("N0").Value
    Me.N1 = .Fields("N1").Value
    Me.N2 = .Fields("N2").Value
    Me.N3 = .Fields("N3").Value
    Me.S0 = .Fields("S0").Value
    Me.S1 = .Fields("S1").Value
    Me.S2 = .Fields("S2").Value
    Me.S3 = .Fields("S3").Value
    Me.PN0 = .Fields("PN0").Value
    Me.PN1 = .Fields("PN1").Value
    Me.PN2 = .Fields("PN2").Value
    Me.PN3 = .Fields("PN3").Value
    Me.PS0 = .Fields("PS0").Value
    Me.PS1 = .Fields("PS1").Value
    Me.PS2 = .Fields("PS2").Value
    Me.PS3 = .Fields("PS3").Value
End With
' Find Gamma Surge
Me.GammaSurge = xfGammaSurge(rstDataOneFan)
End Sub
```

Function xfGammaSurge

```
Function xfGammaSurge(rstDataOneFan) As Double
' This function finds the gamma surge for one fan
Dim i As Integer
With rstDataOneFan
    .MoveLast
    .MoveFirst
    For i = 1 To .RecordCount
        If .Fields("FDID").Value = Me.SurgeFDID Then
            xfGammaSurge = .Fields("Gamma").Value
            Exit For
        End If
        rstDataOneFan.MoveNext
    Next
    If xfGammaSurge = 0 Then
        MsgBox "xfGammaSurge: Unable to set Gamma Surge FDID #" & Me.SurgeFDID
    End If
End With
End Function
```

Function xfGammaPLow

```
Function xfGammaPLow(rstDataOneFan) As Double
' This function finds the gamma low rpm for one fan
Dim i As Integer
With rstDataOneFan
    .MoveLast
    .MoveFirst
    For i = 1 To .RecordCount
        If .Fields("FDID").Value = Me.LowRPMFDID Then
            xfGammaPLow = .Fields("Gamma").Value
            Exit For
        End If
        rstDataOneFan.MoveNext
    Next
    If xfGammaPLow = 0 Then
        MsgBox "xfGammaPLow: Unable to set Gamma for Low RPM FDID #" & Me.SurgeFDID
    End If
End With
End Function
```

Function xfGammaPHigh

```
Function xfGammaPHigh(rstDataOneFan) As Double
' This function finds the gamma high rpm for one fan
Dim i As Integer
With rstDataOneFan
    .MoveLast
    .MoveFirst
    For i = 1 To .RecordCount
        If .Fields("FDID").Value = Me.HighRPMFDID Then
            xfGammaPHigh = .Fields("Gamma").Value
            Exit For
        End If
        rstDataOneFan.MoveNext
    Next
    If xfGammaPHigh = 0 Then
        MsgBox "xfGammaPHigh: Unable to set Gamma for High RPM FDID #" & Me.SurgeFDID
    End If
End With
End Function
```

Function xfSCCMin

```
Function xfSCCMin(rstDataOneFan) As Double
' This function finds the SCC minimum for one fan
Dim i As Integer
With rstDataOneFan
    .MoveLast
    .MoveFirst
    For i = 1 To .RecordCount
        If .Fields("FDID").Value = Me.LowFDID Then
            xfSCCMin = .Fields("SCC").Value
            Exit For
        End If
        rstDataOneFan.MoveNext
    Next
    If xfSCCMin = 0 Then
        MsgBox "xfSCCMin: Unable to set Minimum SCC FDID #" & Me.SurgeFDID
    End If
End With
```

```
End Function
```

Function xfSCCMax

```
Function xfSCCMax(rstDataOneFan) As Double
' This function finds the SCC minimum for one fan
Dim i As Integer
With rstDataOneFan
    .MoveLast
    .MoveFirst
    For i = 1 To .RecordCount
        If .Fields("FDID").Value = Me.HighFDID Then
            xfSCCMax = .Fields("SCC").Value
            Exit For
        End If
        rstDataOneFan.MoveNext
    Next
    If xfSCCMax = 0 Then
        MsgBox "xfSCCMax: Unable to set Maximum SCC FDID #" & Me.SurgeFDID
    End If
End With
End Function
```

Motor Object

```
Option Compare Database
Option Base 1
Option Explicit
' This model comes from the MotorMaster Plus program.  It splits motor
' efficiencies into two regions.
' Below 25% load the efficiency is given by the equation
'   Eff=BHP/(BHP+Fixed Losses)
' Above 25% load the efficiency is given by the 3rd order equation
'   Eff=M0+M1*%Load+M2*%Load^2+M3*%Load^3
Const cbMessage = False ' Turns on dialog boxes
Dim dM0 As Double
Dim dM1 As Double
Dim dM2 As Double
Dim dM3 As Double
Dim dMHP As Double
Dim dFixedLosses As Double
Property Let M0(dM0V As Double)
    dM0 = dM0V
End Property
Property Get M0() As Double
    M0 = dM0
End Property
Property Let M1(dM1V As Double)
    dM1 = dM1V
End Property
Property Get M1() As Double
    M1 = dM1
End Property
Property Let M2(dM2V As Double)
    dM2 = dM2V
End Property
Property Get M2() As Double
    M2 = dM2
End Property
Property Let M3(dM3V As Double)
    dM3 = dM3V
End Property
Property Get M3() As Double
    M3 = dM3
End Property
Property Let MHP(dMHPV As Double)
    dMHP = dMHPV
End Property
Property Get MHP() As Double
    MHP = dMHP
End Property
Property Let FixedLosses(dFixedLossesV As Double)
    dFixedLosses = dFixedLossesV
End Property
Property Get FixedLosses() As Double
    FixedLosses = dFixedLosses
End Property
```

Sub xsGetMotor

```
Sub xsGetMotor(rstHeader As Recordset)
With rstHeader
    Me.M0 = .Fields("M0").Value
    Me.M1 = .Fields("M1").Value
    Me.M2 = .Fields("M2").Value
    Me.M3 = .Fields("M3").Value
    Me.MHP = .Fields("MHP").Value
    Me.FixedLosses = .Fields("FixedLosses").Value
End With
End Sub
```

Function xfEff

```
Function xfEff(dFanBHP As Double) As Double
Dim dPctLoad As Double
dPctLoad = dFanBHP / Me.MHP
If dPctLoad < 0.25 Then
    xfEff = dFanBHP / (dFanBHP + Me.FixedLosses)
Else
    xfEff = Me.M0 + Me.M1 * dPctLoad + Me.M2 * dPctLoad ^ 2 + Me.M3 * dPctLoad ^ 3
End If
End Function
```

Function xfPctLoad

```
Function xfPctLoad(dFanBHP As Double) As Double
xfPctLoad = dFanBHP / Me.MHP
End Function
```

VSD Object

```
Option Compare Database
Option Base 1
Option Explicit
' This model is a 3rd order regression
'   Eff=V0+V1*%Load+V2*%Load^2+V3*%Load^3
' below 25% speed (i.e. 1.56% load) we assume a straight line through 0% effic at 0%
load.
Const cbMessage = False ' Turns on dialog boxes
Dim dV0 As Double
Dim dV1 As Double
Dim dV2 As Double
Dim dV3 As Double

Property Let V0(dV0V As Double)
    dV0 = dV0V
End Property
Property Get V0() As Double
    V0 = dV0
End Property
Property Let V1(dV1V As Double)
    dV1 = dV1V
End Property
Property Get V1() As Double
    V1 = dV1
End Property
Property Let V2(dV2V As Double)
    dV2 = dV2V
End Property
Property Get V2() As Double
    V2 = dV2
End Property
Property Let V3(dV3V As Double)
    dV3 = dV3V
End Property
Property Get V3() As Double
    V3 = dV3
End Property
```

Sub xsGetVSD

```
Sub xsGetVSD(rstHeader As Recordset)
With rstHeader
    Me.V0 = .Fields("V0").Value
    Me.V1 = .Fields("V1").Value
    Me.V2 = .Fields("V2").Value
    Me.V3 = .Fields("V3").Value
End With
```

```
End Sub
```

Function xfEff

```
Function xfEff(dPctLoad As Double) As Double
Dim dEff25 As Double
Dim dM As Double
Dim dLnPctLoad As Double
dLnPctLoad = Log(dPctLoad)
xfEff = Me.V0 + Me.V1 * dLnPctLoad + Me.V2 * dLnPctLoad ^ 2
If dPctLoad < 0.0156 Then '0.0156 is the theoretical PctLoad at 25% speed
    dEff25 = Me.V0 + Me.V1 * 0.0156 + Me.V2 * 0.0156 ^ 2
    dM = dEff25 / 0.0156
    xfEff = dM * dPctLoad
End If

End Function
```

Belt Object

```
Option Compare Database
Option Base 1
Option Explicit
' This model is based on efficiency of a belt split into 3 regions
' Below LowBHP the efficiency is fixed at LowEff
' Above HighBHP the efficiency is fixed at HighEff
' Between LowBHP and HighBHP the efficiency is calculated from:
'    Eff=2.718^(B4*ln(BHP)^4 + B3*ln(BHP)^3 + B2*ln(BHP)^2 + B1*ln(BHP) + B0)
Const cbMessage = False ' Turns on dialog boxes
Dim dLowEff As Double
Dim dLowBHP As Double
Dim dHighBHP As Double
Dim dHighEff As Double
Dim dB0 As Double, dB1 As Double, dB2 As Double, dB3 As Double, dB4 As Double
Property Let LowEff(dLowEffV As Double)
    dLowEff = dLowEffV
End Property
Property Get LowEff() As Double
    LowEff = dLowEff
End Property
Property Let B0(dB0V As Double)
    dB0 = dB0V
End Property
Property Get B0() As Double
    B0 = dB0
End Property
Property Let B1(dB1V As Double)
    dB1 = dB1V
End Property
Property Get B1() As Double
    B1 = dB1
End Property
Property Let B2(dB2V As Double)
    dB2 = dB2V
End Property
Property Get B2() As Double
    B2 = dB2
End Property
Property Let B3(dB3V As Double)
    dB3 = dB3V
End Property
Property Get B3() As Double
    B3 = dB3
End Property
Property Let B4(dB4V As Double)
    dB4 = dB4V
End Property
Property Get B4() As Double
    B4 = dB4
End Property
Property Let LowBHP(dLowBHPV As Double)
    dLowBHP = dLowBHPV
End Property
Property Get LowBHP() As Double
    LowBHP = dLowBHP
End Property
Property Let HighBHP(dHighBHPV As Double)
    dHighBHP = dHighBHPV
End Property
Property Get HighBHP() As Double
```

```
    HighBHP = dHighBHP
End Property
Property Let HighEff(dHighEffV As Double)
    dHighEff = dHighEffV
End Property
Property Get HighEff() As Double
    HighEff = dHighEff
End Property
```

Sub xsGetBelt

```
Sub xsGetBelt(rstHeader As Recordset)
With rstHeader
    Me.HighEff = .Fields("HighEff").Value
    Me.LowEff = .Fields("LowEff").Value
    Me.HighBHP = .Fields("HighBHP").Value
    Me.LowBHP = .Fields("LowBHP").Value
    Me.B0 = .Fields("B0").Value
    Me.B1 = .Fields("B1").Value
    Me.B2 = .Fields("B2").Value
    Me.B3 = .Fields("B3").Value
    Me.B4 = .Fields("B4").Value
End With
End Sub
```

Function xfEff

```
Function xfEff(dBHP As Double) As Double
If dBHP < Me.LowBHP Then
    xfEff = Me.LowEff
ElseIf dBHP > Me.HighBHP Then
    xfEff = Me.HighEff
Else
    xfEff = 2.718 ^ (Me.B0 + Me.B1 * Log(dBHP) + Me.B2 * Log(dBHP) ^ 2 + Me.B3 *
Log(dBHP) ^ 3 + Me.B4 * Log(dBHP) ^ 4)
End If
End Function
```